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EFFECT OF NUTRITION AND AGE AT PHOTOSTIMULATION ON GROWTH AND REPRODUCTION IN FAST AND SLOW FEATHERING TURKEYS

by

VICTORIA ROSE SIKUR

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment

of the

requirements for the degree of Master of Science

in

Animal Science

Department of Agricultural, Food and Nutritional Science

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Effect of Nutrition and Age at Photostimulation on Growth and Reproduction in Fast and Slow Feathering Turkeys submitted by Victoria Rose Sikur in partial fulfillment of the requirements for the degree of Master of Science in Animal Science.

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Abstract

Chickens have been sexed on the basis of feather development at hatching for many years, but the slow feathering gene has only recently been incorporated into a commercial line of turkeys. The effect of increased nutrient density and age at photostimulation on BW, feather cover, carcass composition and reproduction was assessed in fast-feathering (FF) and slow-feathering (SF) turkeys.

The FF birds were heavier than the SF birds from 112 d to 56 wk. Increased nutrient density had a positive effect on BW and frame size during rearing. Breast muscle was increased in SF compared to FF birds. Increased nutrient density increased feather score in SF birds. After photostimulation FF hens had superior reproductive condition compared to SF hens. Delaying photostimulation did not affect total egg production but reduced the number of double-yolked eggs.

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Table of Contents

1.0 INTRODUCTION

1.1 Background 1

1.2 Feathering and production in poultry 3

1.3 Nutrient density and production in poultry 8

1.4 Reproductive physiology and photoperiodism in poultry 12

1.5 Photoperiod-related causes of reduced egg production in birds 15

1.6 Effects of nutrient density and age at photostimulation on reproductive efficiency in poultry 22

1.7 Description of experiments 25

1.8 References 26

2.0 EFFECTS OF NUTRIENT DENSITY ON GROWTH AND CARCASS MORPHOLOGY IN FAST AND SLOW FEATHERING TURKEY POULTS

2.1 Introduction 42

2.2 Materials and Methods 44

2.3 Results and Discussion 48

2.4 References 58

3.0 EFFECTS OF NUTRIENT DENSITY AND AGE AT PHOTOSTIMULATION ON CARCASS MORPHOLOGY AND REPRODUCTIVE EFFICIENCY IN FAST AND SLOW FEATHERING TURKEY HENS

3.1 Introduction 74

3.2 Materials and Methods 77

3.3 Results and Discussion 80

3.4 References 88

4.0 GENERAL DISCUSSION 121

APPENDIX A 124

List of Figures

Figure 1-1. Incorporation of the feather-sexing gene into broiler chickens 40

Figure 1-2. Depiction of differences in wing feather development in day-old poults 41

Figure 2-1. Digital measurements of pectoralis major (P. major) 62

Figure 2-2. Digital measurements from cross-sections of pectoralis major (P. major) 63

Figure 2-3. Feather scores at 32 d. Shown are scores 1, 2, 3, 4, 5 and 6 (fully-feathered) 64

Figure 2-4. Feather scores at 56 d. Shown are scores 1, 2, 3, 4, 5 and 6 (fully-feathered) 65

Figure 3-1. Digital measurements of pectoralis major (P. major) 114

Figure 3-2. Effect of age at photostimulation (29 or 31 wk) on % egg production (± SEM) in turkey hens from 30 to 56 wk of age 115

Figure 3-3. Effect of strain (FF or SF) on % egg production (± SEM) in turkey hens from 30 to 56 wk of age 116

Figure 3-4. Effect of diet (CON or HIGH) on % egg production (± SEM) in turkey hens from 30 to 56 wk of age 117

Figure 3-5. Effect of age at photostimulation (29 or 31 wk) on sequence length in days (± SEM) in turkey hens from 32 to 56 wk of age 118

Figure 3-6. Effect of strain (FF or SF) on sequence length in days (± SEM) in turkey hens from 32 to 56 wk of age 119

Figure 3-7. Effect of diet (CON or HIGH) on sequence length in days (± SEM) in turkey hens from 32 to 56 wk of age 120

List of Tables

Table 2-1. Ingredient and calculated nutrient composition of turkey rations fed from 0 to 198 d of age. 66

Table 2-2. Effect of diet (CON or HIGH) and strain (FF and SF) on BW in turkeys 1 to 198 d of age. 67

Table 2-3. Effect of diet (CON or HIGH) and strain (FF or SF) on feed conversion efficiency in turkeys 14 to 198 d of age. 68

Table 2-4. Effect of diet (CON or HIGH) and strain (FF and SF) on feather score in turkeys 32 to 98 d of age. 69

Table 2-5. Effect of diet (CON or HIGH) and strain (FF or SF) on turkey carcass morphology at 42 d of age. 70

Table 2-6. Effect of diet (CON or HIGH) and strain (FF or SF) on turkey carcass morphology at 84 d of age. 71

Table 2-7. Effect of diet (CON or HIGH) and strain (FF or SF) on breast muscle conformation as determined by digital image analysis in turkeys at 42 d of age. 72

Table 2-8. Effect of diet (CON or HIGH) and strain (FF or SF) on breast muscle conformation as determined by digital image analysis in turkeys at 84 d of age..... 73

Table 3-1. Ingredient and calculated nutrient composition of turkey rations fed from 29 wk to 56 wk of age. 93

Table 3-2. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on BW in turkey hens from 28 wk to 56 wk of age. 94

Table 3-3. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on BW in turkey hens from 28 wk to 56 wk of age. 95

Table 3-4. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on carcass morphology in turkey hens at photostimulation (PSTIM). 96

Table 3-5. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on carcass morphology in turkey hens at photostimulation (PSTIM). 97

Table 3-6. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on carcass morphology in turkey hens at sexual maturity. 98

Table 3-7. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on carcass morphology in turkey hens at sexual maturity. 99

Table 3-8. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on reproductive parameters in turkey hens at sexual maturity. 100

Table 3-9. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on reproductive parameters in turkey hens at sexual maturity. 101

Table 3-10. Effect of diet (CON or HIGH), strain (FF or SF)[2] and age at photostimulation (29 or 31 wk) on carcass morphology in turkey hens at end of lay. 102

Table 3-11. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on carcass morphology in turkey hens at end of lay. 103

Table 3-12. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on reproductive parameters in turkey hens at end of lay. 104

Table 3-13. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on reproductive parameters in turkey hens at end of lay. 105

Table 3-14. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on breast muscle conformation as determined by digital image analysis[4] in turkey hens at

photostimulation (PSTIM). 106

Table 3-15. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on breast muscle conformation as determined by digital image analysis in turkey hens at photostimulation (PSTIM). 107

Table 3-16. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on breast muscle conformation as determined by digital image analysis in turkey hens at sexual maturity. 108

Table 3-17. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on breast muscle conformation as determined by digital image analysis in turkey hens at sexual maturity. 109

Table 3-18. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on breast muscle conformation as determined by digital image analysis in turkey hens at end of lay. 110

Table 3-19. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on breast muscle conformation as determined by digital image analysis in turkey hens at end of lay. 111

Table 3-20. Effect of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on egg production parameters in turkey hens 30 to 56 wk of age. 112

Table 3-21. Interactions of diet (CON or HIGH), strain (FF or SF) and age at photostimulation (29 or 31 wk) on egg production parameters in turkey hens 30 to 56 wk of age. 113

INTRODUCTION

1.1 BACKGROUND

The turkey industry in Canada

The poultry industry comprises 5% of Canada's farmgate receipts or $1.8 billion (Agriculture and Agri-Food Canada, 2001). Turkey production comprises approximately 15% of this amount. Modern poultry production in Canada is highly intensive. This is especially true for turkey production as they take longer to reach production age for meat and hatching egg production than chickens. Meat-type turkeys raised in Alberta are grown in ventilated, light-tight facilities until market age. There are currently over 500 producers nationwide producing over 150 million kg of turkey meat (Canadian Turkey Marketing Agency, 2000).

One method used to increase production efficiency in broiler chicken production is feather-sexing or sexing on the day of hatch by differential rates of wing feather development in genetically fast- and slow-feathering birds. This has not yet been realized in commercial turkey production. Feather-sexing may reduce overall turkey production costs. What follows is a detailed discussion of relevant physiological processes, as well as previous and current approaches aimed at improving production in domestic poultry.

Sex-separate rearing

Sex-separate rearing is commonly practiced in poultry production. In turkey production, males and females are marketed at different ages after reaching their optimum respective body weights. Raising male and female birds separately optimizes growth and feed conversion by minimizing feed competition between genders, and by allowing feeding of larger and more efficient male birds specifically according to their

nutritional needs. It may also contribute to increased BW uniformity as nutrient and stocking density can be adjusted for differences in growth and feed efficiency between genders (Veerapen and Driver, 1999). This practice is most effective when implemented from the day of hatch.

Sexing in poultry

In general, birds lack external gender-specific characteristics at hatch such as visible differences in genitalia, color or body weight. Commercial poultry can be vent-sexed, which involves everting the vent through applied pressure, and inspection of the inner vent morphology to determine gender at hatch. This method is costly as specialized training is required for vent-sexing. It is also error-prone and can increase bird stress levels. External stressors can have negative effects on growth later in life (Korver et al., 1998). Autosexing, based on feather cover or feather development, can be employed. Sexing based on feather color is not particularly useful for commercial use, as virtually all commercial birds have white feathers to prevent epidermal blemishes on white or yellow skin occurring from dark-colored feather pigment at processing. Feather sexing is another method used to separate genders of birds at hatch. Broiler chickens with this gene have obvious differences in primary and secondary wing feather length at hatch and are easily distinguishable. Feather sexing based on feather development at hatch is commonly used in chicken production because it is faster, more economical and less stressful for chicks compared to vent-sexing (Harris et al., 1984).

1.2 FEATHERING AND PRODUCTION IN POULTRY

Feather growth and structure

Feathers are important for flight, identification and protection. Feathers are composed of 90% protein (Leeson and Summers, 1997), and approximately 16.5% of the dry mass of a whole feather is made of keratin (Zakzrewska, 1995). Keratin is rich in cystine, therefore the sulfur-containing amino acids (SAA) cystine and methionine are very important for feather growth. Energy is required for feather maintenance and growth through keratinization. Keratinization is a process whereby the surface cells compact, crosslink, and die, resulting in the formation of scale-like structures on the apical surface. The process of keratinization is similar in both feather and hair growth, different only in the actual arrangement of the cells involved in keratinization (Harrap and Woods, 1967).

Variations in rate of feather development

Feather growth can be affected by several factors, including non-genetic factors such as diet (Leeson and Summers, 1997), as well as genetic factors. Several genes related to feather development in the chicken have been described and can be classified by mode of inheritance. These are autosomal, sex-linked, recessive or dominant genes, which have been reviewed in detail by Zakrzewska (1995). Autosomal recessive genes include 'retarded feather growth' (Jones and Hutt, 1946) and 'Ottawa naked' (Crawford et al., 1982). Warren (1925) described the autosomal and incompletely dominant gene 'flightless' in chickens. This gene affected the development of larger feathers, causing them to break with less resistance than feathers from normal chickens. Marlow and Caldwell (1934) reported that x-ray examination showed that feathers from these birds had a less definite structure, as well as decreased cystine and phosphorus content when

compared to feathers from normal birds. A sex-linked recessive gene in chickens is sex-linked naked (Somes, 1978). These birds were shown to have very delayed feather growth, several featherless areas and modified feather structure compared to birds without this gene.

In chickens, a sex-linked dominant gene, specifically the K locus, affects rate of feather development. Serebrovsky (1922) found that chickens having a gene he called 'suke' (slow) had significantly less feathering at hatch and less subsequent feather cover during rearing than their allelic 'asuke' counterparts. Warren (1925) found that the gene was sex-linked, and had a potential benefit for separating birds by gender. This locus was designated as "K" for 'kurzer Flugel' or slow-feathering by Hertwig and Rittershaus (1929). The K allele is dominant to k^+. Briefly, at the grandparent level, male birds can be heterozygous (K/k^+) or homozygous for slow- feathering (K/K) or homozygous for fast-feathering (k^+/k^+). Females are hemizygous for slow-feathering (K/W) or fast-feathering (k^+/W). From the grandparent level, parents for the terminal cross are chosen as follows. The male must be homozygous fast-feathering (k^+/k^+), and the female must be slow-feathering (K/W). The progeny of this cross are then termed "feather-sexable", that is, 100% of females are fast-feathering (k^+/W), or FF, and 100% of males are slow-feathering (K/K), or SF (Figure 1-1). The differences in wing feather development at hatching in poults with the slow-feathering gene are depicted in Figure 1-2.

Genes affecting rate of feather development are also present in turkeys, but have been much less studied than similar genes in chickens. Autosomal recessive traits include 'hairy' (Smyth, 1954) and 'naked' (Poole and Mardsen, 1961). Asmundson and Abbott (1961) described a sex-linked dominant trait in turkeys termed 'late feathering'. The first

gene of this type was recognized in turkeys in the early 1960s, but this research indicated that the gene was not suitable for commercial use (Asmundson and Abbott, 1961) and the line carrying the gene was terminated. Even though these first mutant birds were deemed undesirable for production, the researchers noted that (as may have been the case with the first slow-feathering chickens) there was wide variation in feather development of individual birds at 8 wk. Currently, commercial breeders in the chicken industry are very highly selected for traits that are desirable in the poultry industry, such as breast muscle yield. Primary breeder companies put forward different "products", or birds with specific combinations of production-related traits such as increased feed efficiency annually in response to market and producer demand. Therefore, a gene specifically affecting a trait such as feather development would currently act within a different genetic background than when previously studied. The interaction of the background genome and genes related to feathering may have modified the effects of the slow-feathering gene in chickens.

A gene described as 'inhibited feathering' in turkeys, which was different from gene described by Asmundson and Abbott (1961), was studied by Zakrzewska (1995). It was shown that the gene affected several aspects of feather growth, including number, size and structure of feathers. There was a range of expression in terms of feather cover in these birds, ranging from virtual "barebacks" to relatively well-feathered individuals. Feather amino acid composition was modified, causing feathers to break easily. This was possibly due to low concentrations of leucine and isoleucine (branched-chain amino acids) in the feathers from inhibited feathering turkeys. Blood chemistry was changed compared to commercial turkeys, accounting for some of the differences noted in

metabolism of SF turkeys (Zakzrewska, 1995). This variability described by Zakzrewska (1995) with regard to the SF phenotype makes it possible to select and cross birds that have commercially useful traits, such as increased feathering and efficient BW gain, which has been accomplished in broiler chicken production (Chambers et al., 1993).

Effects of feathering rate on production traits

The gene used in feather sexing on wing feather length is based on sex-linked genetics, and the associated pleiotropic effects on rate of feathering, feather cover, BW gain and egg production have been considered in past research. Feather development is delayed in the male feather-sexable chicken broiler at day of hatch (Bartov et al., 1991). Feather cover was reduced in both male and female late-feathering broiler chickens at approximately 3 to 4 wk (McDougald and Keshavarz, 1984; Dunnington and Siegel, 1986; Lowe and Merkley 1986) in late-feathering broiler chickens. Feathering is also delayed in turkeys carrying similar genes (Asmundson and Abbott, 1961; Zakzrewska, 1995).

Lack of feather cover can result in bare patches of skin, leaving the skin susceptible to scratching and breakage. This weakening of the skin's barrier may contribute to diseases such as cellulitis (Elfadil et al., 1996). Decreased feather cover can result in increased metabolic requirements as thermal insulation is decreased. This has been observed in chicks that were artificially de-feathered or lacking in feathers due to genetics (Wekstein and Zolman, 1970; Prijono, 1991; Özkan et al., 2002). Some studies report no difference in growth due to genetic feathering type (Hurry and Nordskog, 1953; Saeki and Katsuragi, 1961; Lowe et al., 1965). Others have reported that better growth is seen in birds with normal feather cover (Warren and Payne, 1945; Plumart and Mueller,

1954; Asmundson and Abbott, 1961; Wekstein and Zolman, 1970; Dunnington and Siegel, 1986; Zakzrewska, 1995). Differences in growth curves have also been noted by Sheridan and McDonald (1963), who found that slow-feathering (SF) chickens were heavier than fast-feathering (FF) chickens at 5 wk, and lighter than FF chickens at 10 wk. Sheridan and McDonald (1963) stated that their observations could be the result of competition between feather and muscle growth for arginine and cysteine during the phase of rapid growth in these birds. The SF birds were shown to have less feather growth than FF birds earlier in life and may have been able to partition more dietary protein into muscle. Similarily, Lowe and Merkley (1986) found that SF male broiler chickens had increased BW compared to FF males at 3 wk. Overall, SF birds may have differing proportions of feathers and muscle by mass (both of which are composed primarily of protein) compared to birds with normal feather cover. Therefore, they may respond uniquely to differences in protein intake.

The slow-feathering gene may also affect egg production (Chambers et al., 1993). Decreased egg production has been reported in SF stocks, including layers (Harris et al., 1984; Saleh et al., 1987), broiler breeders (O'Sullivan et al., 1991) and turkeys (Zakrzewska, 1995) compared to FF birds. This may be partially attributed to higher infection and shedding rates for leukosis viruses (ALV) in SF than in FF White Leghorn dam lines. In egg-type and broiler breeder hens, decreased production has been further connected to the expression of the 'ev21' viral gene, which is closely associated with the K^+ allele and encodes for infectious lymphoid leukosis virus (Harris et al., 1984; O'Sullivan et al. 1991). However, Dunnington and Siegel (1986) and Katanbaf et al. (1989) concluded that reproductive factors were minimally affected by sex-linked

feathering alleles in broiler breeder stock. Zakrzewska (1995) reported that inhibited feathering turkeys showed decreased overall reproductive efficiency, including decreased egg production, when compared to normal turkeys. This may have partially been due to increased stress in inhibited feathering turkeys. Several factors supporting this conclusion were explored by Zakzrewska (1995), including increased blood alkaline phosphatase from increased nervousness and stress (Singh and Balaine, 1983), increased plasma sodium concentration from increased water loss through the skin because of lack of feather cover (Peguri and Coon, 1993), and higher levels of plasma glucose, suggesting differences in the metabolism of inhibited feathering and normal feather turkeys.

Inconsistent results with regard to the SF phenotype in various types of stocks may be due to differences in research techniques related to diet and environment, as well as changes in the genetic background in domestic poultry over time. The K gene may also have been interacting with the rest of the genome. (Chambers et al., 1993).

1.3 NUTRIENT DENSITY AND PRODUCTION IN POULTRY

The general nutrient requirements of domestic chickens and turkeys are well known. Nutrient requirements can vary depending on numerous factors such as age, stage of production, feed intake and formulation, environmental factors and genetic strain.

Protein is important for numerous functions, including formation of body tissues (fibrous proteins), maintenance of homeostasis (globular proteins) and transportation of energy and nutrients within the bloodstream (conjugated proteins), and many others (Leeson and Summers, 2001). Protein requirements for poultry vary according to several factors, including protein quality , species, age and protein intake. Protein quality in feed is defined by its quantity within the feed, its digestibility, and its amino acid composition.

Breeder turkeys require more protein and take longer to reach market age than chickens due to decreased efficiency of protein utilization (Leeson and Summers, 1997). Protein deposition is also affected by the amount of available dietary energy, as protein metabolism processes require energy (Leeson and Summers, 2001). For example, Buttery et al. (1973) estimated that protein anabolism, turnover and uric acid synthesis for a 900 g chick was approximately 11% of ME intake.

Protein intake is affected by dietary energy level; as energy level increases, feed intake generally decreases, so subsequent adjustments in protein levels must be made to avoid protein restriction. In order to formulate diets that will be utilized more efficiently in terms of feed costs and nitrogen excretion, they may be formulated based on the bird's amino acid requirements (using lysine requirements as a standard) instead of general crude protein requirements. Amino acid requirements are relatively similar for domestic poultry, but are affected by the age of the bird and its carcass composition as younger and meat-type birds will likely have faster growth and increased percentages of carcass protein relative to older birds or breeder stock (Leeson and Summers, 2001). Additionally, most amino acids required for growth and metabolism are formed endogenously through tissue catabolism, with 30% to 40% of amino acids being obtained from the diet (Leeson and Summers, 2001). The focus of this review is on dietary crude protein level and proportionate amino acid levels because much remains to be elucidated with regard to complete amino acid requirements of domestic fowl, and the purpose of these trials was to characterize the particular strain responses of turkeys to commercial dietary formulations.

Nutrient density and growth

There are several situations where protein may be increased above maintenance levels. Birds in the early rearing stages grow rapidly (Sheridan and McDonald, 1963) and need dietary protein and energy levels over that required for maintenance to maintain muscle growth until shipping. Additional protein is required for growth and production in meat-type birds and breeders, respectively.

Supplemental protein may allow body condition to be maintained in situations where metabolic requirements are increased, such as cold stress. Birds in this situation maintain homeothermy by adjusting both their behavior and their internal heat production. These adjustments include feather fluffing, reducing unnecessary movement, and shivering to produce internal heat. Regulation of body temperature is important for maintaining feed intake and efficiency. Decreased environmental temperature or thermal insulation such as feathers can also result in increased metabolic requirements, leaving less energy for growth. Maintenance requirements for energy increased and feed efficiency decreased in broilers as environmental temperature decreased below an optimal thermoneutral zone (Hurwitz et al., 1980). Wekstein and Zolman (1970) found increased rates of cloacal cooling in chicks that were artificially defeathered or genetically lacking feathers compared to control chicks. Skin surface temperatures were significantly lower in SF females from a broiler parent stock than in FF birds at 17, 21 and 24 d (Dunnington and Siegel, 1986).

Harris et al. (1980) found that the degree of feathering was positively related to the health of broilers. Birds with less feather cover may have greater exposure to disease leading to modified immune responses. These include decreased feed consumption,

increased white blood cell production, muscle degradation and increased metabolic rate and fever. Immune responses may result in reduced growth during the rearing period (Korver et al., 1998). Lack of feather cover can result in bare patches of skin, leaving the skin susceptible to scratching and breakage. This weakening of the skin's barrier may contribute to diseases such as cellulitis (Elfadil et al., 1996). However, Dunnington et al. (1987) showed that SF broiler chickens did not have differences in BW when fed ad libitum, nor did they have increased antibody response to mild stressors when compared to FF birds.

Increasing dietary protein from inadequate or maintenance levels is thought to have positive effects on growth and feathering. Increased BW was reported in pheasants (Woodard et al., 1977) and meat-type chickens (Lowe and Merkley, 1986) fed above maintenance levels of protein. Broiler breeder BW was also increased in response to increased dietary protein, which was expected in feed-restricted stock (Yaissle and Lilburn, 1998). As well, increased protein significantly improved feathering in pheasants at 5 wk, the improvement diminishing as the birds aged (Woodard et. al., 1977).

Because feathering is strongly dependent on the process of keratinization, it was thought that supplementing dietary sulphur-containing amino acids (SAA) would increase feather growth. Wool growth was increased in sheep receiving supplements of SAA. (Gillespie, 1991). Normally, about 2% of dietary methionine and 25% of dietary cystine is required for feather development (Leeson and Summers, 1997). However, methionine is important for body growth and development as well, so if carcass growth is unaltered while feather growth is affected for reasons associated with SAA levels, then cystine should be the main consideration (Leeson and Summers, 1997). McDonald

(1958) indicated that SF birds had increased cystine requirements compared to FF birds. Methionine supplemented at 1.09% of the diet significantly improved feather scores in SF turkeys 0 to 8 wk of age compared to the same birds fed methionine at 0.54%, indicating an improvement in feather cover (Zakrzewska, 1995). However, decreased BW was seen in conventional and SF type turkeys with methionine supplementation at 0.62% and 1.44%, which is two and four times the suggested amount of 0.32% (NRC, 1994). Amino acid levels were not balanced in the diets containing increased methionine, so this may have been the cause of decreased BW. However, SF and FF birds responded similarily to the diets supplemented with methionine, suggesting that methionine metabolism was similar in the two strains under these conditions. A level of methionine twice that or more of recommended levels was not recommended for birds, especially those with genetic traits of reduced feathering as they are thought to convert less methionine to cystine through reduced feathering processes (Miller et al., 1960; Abbott et al., 1962). Previous work showed improved feather growth in inhibited feathering turkeys when zinc was supplemented in the diet (Zakrzewska, 1995), which could be expected as zinc deficiency in birds is characterized by retarded growth and poor feathering (Leeson and Summers, 2001).

1.4 REPRODUCTIVE PHYSIOLOGY AND PHOTOPERIODISM IN POULTRY

Physiology of egg production

The reproductive tract of the bird consists of a single functional ovary and an oviduct. This ovary is located on the left side of the bird, anterior and ventral to the kidney. The right ovary is present in the female as an embryo and after hatching , but does not usually develop fully in the manner that the left ovary does. Follicles in the

ovary can be classified by their diameter (Robinson and Etches, 1986). The ovary in the domestic chicken consists of seven to nine preovulatory large yellow follicles (LYF) that are at least 10 mm in diameter, and a large pool of developing small yellow follicles (SYF) 5 to 10 mm in diameter. Large white follicles (LWF) are 3 to 5 mm in diameter, and small white follicles (SWF) are less than 3 mm in diameter. In turkeys, the ovary is usually heavier and contains nine to eleven LYF (Hocking et al., 1987). The LYF are arranged in a hierarchy in both species, where F1 is the largest follicle and ovulates first unless it undergoes atresia.

Female turkeys reach sexual maturity approximately 2 wk after being photostimulated if all other thresholds for the start of egg production have been satisfied, including age, body weight and body composition (Brody et al., 1984; Zelenka et al., 1986; Katanbaf et al., 1989). During this time after photostimulation, the reproductive tract, consisting of the ovary and the oviduct, enlarges rapidly. The hypothalamus responds to increased daylength and secretes gonadotropin-secreting hormone (GnRH). This stimulates the anterior pituitary to produce luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Yolk proteins are formed in the liver in response to estrogen and transported to the ova via the circulatory system (Schjeide et al. 1963). Small follicles are recruited into a pool of developing follicles that eventually grow in a hierarchy if atresia does not occur, and the largest follicle is ovulated in response to an LH surge about every 26 hours. The laying cycle continues for approximately 25 wk with egg production gradually declining as birds become photorefractory in response to an extended period of photostimulatory lighting.

Photoperiod

Temperate birds respond to seasonal changes in day length, initiating reproductive behavior naturally in the spring when days lengthen and offspring are more likely to survive. Domesticated poultry and other seasonal breeders such as sheep raised indoors can be stimulated using increasing periods of artificial light. The effect of daylength on reproduction in birds has been known for some time (Etches, 1984). Daylength and intensity of light are two factors related to photoperiod determining the initiation of reproduction function and the ensuing rate of lay in females (Etches, 1984). Egg production was found to occur independent of bird age, and was instead related to stage of reproductive cycle, as shown by similar egg production curves in young (30 wk) and old (70 wk) hens that were kept on short days and then photostimulated at these two ages.

While the concept of how light affects reproduction in the bird is generally accepted, some aspects remain unclear. Light is emitted as photons, and birds change this energy into neural impulses using photoreceptors. The exact location of all photoreceptors in the bird is unknown. Light perception was first isolated to the head area, as birds with their heads completely covered did not respond to increased daylength (Etches, 1984). Impeding the passage of light through the skin surrounding the skull reduced response to photostimulation (Etches, 1984). Genetically blind birds were shown to have a functional photostimulatory response (Ali and Cheng, 1985). The retina of the eye was shown to be not essential to light perception for reproductive function in chickens (Siopes and Wilson, 1980).

Specific intracranial locations for photoreceptors have been investigated. The pineal gland was identified as a possible link in the response to photostimulation

(Nakahara et al., 1997), as its pinealocytes are derived from photoreceptors and can use serotonin to synthesize melatonin (Oksche, 1980). However, studies with several avian species showed that pinealectomy during photostimulation did not terminate reproductive function (Harrison and Becker, 1969; Homma et al., 1967), indicating that photoreceptors were located in other areas as well as the pineal gland. Benoit (1964) first indicated the hypothalamus as a site of light perception. It was found that direct application of light to the hypothalamus stimulated testicular growth and egg production (Etches, 1984). Additionally, response to photostimulation was impaired when the hypothalamus was inactivated (Etches, 1984), indicating the hypothalamus as one of the major sites of photoreceptors in the bird. However, the exact locations of all photoreceptors both outside and within the hypothalamus have not been established.

1.5 PHOTOPERIOD-RELATED CAUSES OF REDUCED EGG PRODUCTION IN BIRDS

An understanding of photoperiodic response in birds can aid in maximizing reproductive efficiency. In nature, birds physiologically adapt to seasons that are favorable in terms of climate and food supply for reproduction and raising young. The major factor affecting timing of reproduction in temperate birds is the annual change in daylength (Rowan, 1929). The photoperiodic response is the sum of photoinhibitory and photostimulatory responses (Etches, 1984). Birds use circadian rhythms to differentiate between short and long days (Follett, 1982). A short daylength is defined as one that is not sufficiently long enough to evoke a reproductive response. The light must also be of sufficient intensity to stimulate reproduction (Etches, 1984). Hence, daylength and light intensity are important parts of photoperiod regimes for efficient reproductive function in

commercial breeder stock. After peak egg production in domestic chickens and turkeys, the level of production normally undergoes a gradual decline until the end of the cycle. A major reason for decreasing egg production in photosensitive species of birds is extended exposure to photostimulatory daylength, which results in a lack of ability to transform light energy into neural energy, or photorefractoriness (PR) (Sharp, 1992).

Another factor in decreased egg production in several bird species is the onset of incubation behavior, also known as broodiness. Incubation refers to the behavior and physiological state associated with the care of unhatched eggs in a clutch. Brooding refers to care of young birds. Incubation behavior is a heritable trait that results from behavior-induced changes in the hen's hormonal balance, which causes the ovary to regress and egg production to halt (Bacon et al., 1983). These areas are briefly explored with respect to their causes, effects on reproduction, and methods of control.

Photorefractoriness

Photorefractoriness (PR) refers to the state in which a bird becomes reproductively inactive even when exposed to photostimulatory daylength. This state is characterized by the gradual cessation of egg production, regression of the reproductive organs, and failure of the bird to maintain gonadotropic secretion. Egg production decreases in older chickens due to a decreased number of LYF (Williams and Sharp, 1978). The rate of follicular recruitment into the LYF hierarchy decreases, and the interval between ovulations increase as the production cycle progresses (Bahr and Palmer, 1989; Liu et al., 2002). The exposure of birds to a daylength longer that that required for photostimulation, or the critical daylength, may also contribute to the onset of PR (Sharp, 1993). Starlings (*Sturnus vulgaris*) exposed to a photoperiod of 18L:6D

showed a subsequent brief period of reproductive activity and a rapid onset of PR, essentially "burning out" very quickly (Dawson and Goldsmith, 1983). A lighting regime of 11L:13D in the same study resulted in delayed initiation of egg production, but no occurrence of PR. The decrease in gonadotropin levels prior to the onset of PR may be attributed to the anterior pituitary being less able to secrete LH and FSH in response to GnRH from the hypothalamus as egg production declines (Etches, 1984). However, inactivity of the anterior pituitary may be a direct result of a lower concentration of GnRH being secreted from the hypothalamus (Nicholls et al., 1988). Hypothalamic GnRH concentration was decreased in starlings and egg-type hens as they became photorefractory (Dawson et al., 1985; Sharp et al., 1990). It has also been shown in numerous species that exogenous GnRH given during a period of minimal gonadotropic activity stimulates the pituitary to release high levels of LH, and that the pituitary responses of photosensitive and photorefractory individuals were relatively similar (Sharp and Lea, 1981; Wingfield et al., 1979). This indicates the probable role of hypothalamic GnRH as the main factor for the onset of PR.

Factors affecting the hypothalamus and onset of PR

The factors influencing the hypothalamus with regard to PR have been reviewed by Nicholls et al. (1988) and Sharp (1993; 1996). Neuronal or hormonal inputs to the hypothalamus affect the onset of PR. Once daylength has reached or surpassed the genetically determined critical limit, photoperiodic information is interpreted as both stimulatory and inhibitory inputs to the hypothalamus. Initially after photostimulation, stimulatory inputs are usually dominant and reproductive processes commence. As the reproductive cycle progresses and stimulatory daylength is maintained, inhibitory inputs

become gradually more dominant and PR as well as regression of reproductive organs occur. In species that are absolutely photorefractory, the photorefractory status persists until after the daylength is shortened below that of the critical limit and photosensitivity can be regained.

Thyroid hormones have been indicated as factors affecting the programming of PR within a few weeks after photostimulation in sparrows (*Spizella arborea*) and starlings (*Sturnus vulgaris*) (Nicholls et al., 1988; Wilson and Reinhert, 2000; Dawson et al., 2001). The thyroid may also be involved in PR programming in commercial turkeys, but to a lesser extent as selection for growth and reproduction may have resulted in inadvertent selection for mechanisms that inhibit PR (Proudman and Siopes, 2002). The levels of thyroid hormones affect several areas of development, including feather growth, neural transmission, neuronal development and reproduction (Capen, 1993). The role of thyroxine and triiodothyronine in reproduction has been observed through studies of thyroidectomy or exogenous administration of these hormones. Modification of thyroid activity as a partial response to stress has been implicated as one factor resulting in reduced egg production in inhibited-feathering turkeys (Zakzrewska, 1995). Increased thyroid hormone levels have been shown in birds exposed to long daylengths resulting in PR (Sharp and Klandorf, 1981; Klandorf et al., 1982; Dawson, 1984). Thyroidectomy resulted in the absence of PR in starlings (Goldsmith and Nicholls, 1984). It was also observed with thyroidectomy that hypothalamic levels of GnRH remained high, prolactin levels were greatly reduced, and post-nuptial molt was prevented, all factors associated with PR (Dawson et al., 1985; Goldsmith and Nicholls, 1984). However, thyroxine adminstered to birds exposed to moderately photostimulatory daylength (associated with

slower reproductive development and decreased incidence of PR) did not result in PR until very large amounts were given (Goldsmith and Nicholls, 1984). In the review by Nicholls et al. (1988), it was concluded that thyroid hormones are involved in the development of PR, but are not the primary cause of it.

Absolute and relative photorefractoriness

The degree of PR is species-specific in photosensitive species of birds (Follett, 1988). Some species such as the white-crowned sparrow (*Zonotrichia leucophrys gambelii*) exhibit absolute PR (King et al., 1966) and others, such as the Japanese quail *(Coturnix coturnix japonica)*, are thought to be relatively photorefractory (Robinson and Follett, 1982). The difference lies in what is required to re-initiate egg production after an extended period of long days and cessation of laying; the former terminates reproduction even if daylength is sufficiently long, then resumes breeding after exposure to relatively short day lengths (Burger, 1947; Hamner, 1968). Without exposure to short daylength, PR can persist perhaps indefinitely and certainly for very long periods (Nicholls et al., 1988). In the domestic hen, 10 to 12 wk of exposure to short days is sufficient to restore photosensitivity (Etches, 1984), and in the starling, 25 to 35 d has been reported (Goldsmith and Nicholls, 1984). The quail, termed a relatively photorefractory species, also experiences PR after an extended photostimulatory regime, but regains reproductive competence after exposure to extended day length (i.e. 20L: 4D), with no requirement for short days as seen with absolute PR (Nicholls et al., 1988). In this situation, the presence PR is not strong enough to stop egg production indefinitely as described with absolute PR (Siopes, 2001). Relative PR has been suggested to precede absolute PR, and to be a less extreme form of absolute PR (Wilson and Reinert, 1999).

The turkey hen can exhibit both absolute and relative PR (Siopes, 2001; Siopes 2002; Proudman and Siopes, 2002). This condition and its management has been extensively researched (Harper and Parker, 1957; Ogasawara et al., 1962; Siopes, 1991). In general, PR occurs at a relatively high frequency in turkeys, but the onset is highly variable as well, and is usually not permanent (Siopes, 2001). There is no way to permanently control PR, but it can be partially controlled by exposure to short daylength. This management technique is usually commercially implemented in the prelay period to maximize reproductive efficiency (Siopes, 1989).

Incubation behavior

The incidence of incubation behavior, or broodiness, is a common genetic trait in birds and is a major cause of decreased egg production in chickens (Sharp et al., 1988) and turkeys (El Halawani and Rozenboim, 1993). It is characterized by increased nesting behavior and cessation of egg production. The main factor associated with broodiness is high circulating prolactin concentration or hyperprolactinemia (Sharp et al., 1989; Proudman and Wentworth, 1996; Caldwell et al., 1999). Approximately 10 d before the onset of broodiness, LH and progesterone levels were reported to decrease due to follicular regression, with a concurrent increase in prolactin (Proudman and Opel, 1981). Prolactin gene expression was shown to increase as well during this time (Wong et al., 1991). The secretion of prolactin was observed to be controlled at the level of the hypothalamus and the pituitary, demonstrated by large increases of circulating prolactin secretion after electrical stimulation of these areas in the turkey (El Halawani et al., 1987). Intracranial infusion of prolactin resulted in persistent nesting behavior 3 to 4 d after treatment in turkeys (Youngren et al., 1991). The posterior pituitary was isolated as a regulator of prolactin secretion (El Halawani et al., 1992). At the cellular level,

increased prolactin secretion resulted from increased lactotrophic cell recruitment and hypertrophy and decreased somatotrophic cell numbers were reported in turkeys that were incubating compared to those that were laying (Ramesh et al., 1996). The decrease in somatotrophic cells was attributed to these cells possibly altering to lactotrophic form, as seen in mammalian and turkey pituitaries (Porter et al., 1991; Ramesh et al., 1994).

Prolactin release was suggested to be related to tactile stimulation of the edematous, defeathered brood patch located on the underside of the turkey in the lower breast area to within 1.25 to 2.5 cm from the cloaca and to within 5 cm of the wing (Patel, 1926; Book et al., 1991). Nesting activity has been identified as a source of stimulation of the brood patch area, as prolactin levels decrease when nesting access is denied, but increase once access is regained (El Halawani and Rozenboim, 1993). Book et al. (1991) identified the peripheral nervous input to the brood patch from eight nerves arising from thoracic vertebra 3 to synsacrothoracic vertebra 1. Anesthetizing the brood patch area decreased prolactin levels in mallard ducks (*Anas platyrhynchos*) displaying incubation behavior, but effects on incubation behavior were inconclusive (Hall and Goldsmith, 1983). Turkey hens with denervated brood patches stayed on the nest for a shorter time, had lower prolactin levels, maintained egg production and did not display incubation behavior compared to control hens (Book et al., 1991). From previous work, it can be stated that incubation behavior is induced through stimulation of the brood patch during nesting activity and is a major factor in reduced egg production in turkeys.

Mechanisms of action

Increased prolactin may result in reduced levels of gonadotropic hormones, resulting in the onset of incubation behavior (El Halawani et al., 1988). High levels of

prolactin may reduce progesterone levels (Reddy et al., 2002) by stimulating the enzyme hydroxysteroid dehydrogenase (Wang et al., 1979). The production of estradiol-17ß may also be affected by increased prolactin due to interference with the synthesis of androgens or aromatase activity (Gilbert, 1971; Robinson et al., 1990). Low levels of prolactin, then, may be associated with improved persistency of lay, and overall increased egg production (Guemene and Williams, 1994).

Methods of control

Increased prolactin secretion or a hyperprolactenimic state is related to diminshed dopaminergic activity and increased levels of the neuropeptidergic prolactin-releasing factor (PRF) vasoactive intestinal peptide (VIP) in the hypothalamus (El Halawani and Rozenboim, 1993). The maintenance of prolactin release is associated with VIP, as indicated by normal levels of egg production and fewer nest visits in turkeys immunized with VIP compared to those that were not immunized (Caldwell et al., 1999; El Halawani et al., 2000). Prolactin gene expression was reduced after VIP immunoneutralization (Tong et al., 1998). Inactivation of prolactin via bromocriptine, a dopamine agonist, resulted in longer ovulatory sequences and increased egg production in turkeys (Reddy et al., 2001). The suggested mechanism is that an decrease of dopaminergic activity reduced secretion of prolactin releasing hormone and VIP (Youngren et al., 1998).

1.6 EFFECTS OF NUTRIENT DENSITY AND AGE OF PHOTOSTIMULATION ON REPRODUCTIVE EFFICIENCY IN POULTRY

Nutrient density and reproduction

One approach to achieving adequate thresholds for reproduction is to increase dietary protein intake to satisfy or exceed protein requirements. Increased dietary protein

during the pre-lay period (Cave 1984; Brake et. al. 1985) and during production (Bowmaker and Gous, 1989) was shown to increase egg production in broiler breeders. Ad libitum-fed turkeys had more yellow follicles due to increased follicular recruitment than restricted-fed turkeys (Hocking et al., 1992). This was also the case in feed-restricted broiler breeders fed above standard feeding curves (Renema et al., 1995; Robinson et al., 1998; Renema et al., 2001a; Renema et al., 2001b). Hocking (1993) reported that the number of LYF at sexual maturity was directly proportional to BW. This resulted in an increased percent of carcass fat, partially due to more ovarian follicles producing more estrogen in ad-libitum fed birds. Increased dietary protein to levels nearing ad libitum during production allows for adequate protein for maintenance of body nutrient levels and processes related to egg formation (i.e., shell formation and albumen production) (Renema et al., 2001a; Renema et al., 2001b; Joseph et al, 2002).

Age at photostimulation and reproductive efficiency

Delaying photostimulation for a short time is another approach to improve egg production. Later photostimulation has no detrimental effect on production in broiler breeders (Yuan et al., 1994; Robinson et al., 1996; Nøddegaard et al., 2000) and increased frame size, muscle growth and organ development (Yuan et al., 1994; Robinson et al., 1996). Early egg size was increased in broiler breeders (Joseph et al., 2002), and multiple ovulations were reduced in turkeys (Woodard et al., 1974) that were photostimuated later. This decrease in non-settable eggs in the turkey was attributed to a decreased multiple hierarchies on the ovary (Hocking, 1992). Siopes (1999) observed a decrease in mean hen-day egg production over a 54-wk period in hens photostimulated at 30 wk compared to hens photostimulated at 26 wk, and this was attributed to later-

photostimulated birds being in production for a shorter time than birds photostimulated earlier. Egg weight was reduced throughout lay in birds photostimulated earlier in the same trial. Early photostimulation is associated with small early egg size in turkeys (Hocking, 1992; Siopes, 1992). Delaying photostimulation allows feed-restricted breeder hens to respond to light stimulation in a more uniform manner as thresholds for sexual maturity are reached in a higher percentage of the flock. Overall, egg production may be increased in feed-restricted birds by delaying photostimulation by way of increased flock uniformity, early egg size, settable egg production and persistency of lay (Renema et al., 2001a; Renema et al., 2001b) Nonbiological benefits achieved by this approach include decreased electricity and feed costs (Siopes, 1999).

1.7 DESCRIPTION OF EXPERIMENTS

Objective

This trial was conducted in two parts to characterize the growth and reproductive potential of SF turkeys compared to commercial FF turkeys. The response of both turkey strains with regard to carcass growth and reproductive efficiency to variations in nutrient density and age at photostimulation was evaluated.

Experiments

1. **Objective:** To determine the effect of increased nutrient density on growth and feather cover in FF and SF turkey poults.

   Description: Two strains of turkey poults (FF and SF) were reared to 28 wk on either a conventional diet formulated to industry standards or a diet that was approximately 10% higher in protein and energy compared to the conventional diet. Carcass morphology, skeletal growth and feather cover was compared between strains and between feeding regimens.

2. **Objective:** To determine the effect of increased nutrient density and age at photostimulation on carcass morphology and reproductive efficiency in FF and SF turkey hens.

   Description: Two strains of turkey hens (FF and SF) from Experiment 1 were photostimulated at either 29 wk or 31 wk, and fed either a conventional breeder diet formulated to industry standards or a diet that was, in comparison to the conventional diet, approximately 10% higher in protein and energy to 56 wk. Carcass morphology and frame size was compared at three ages, and individual egg production was compared over the laying cycle. All comparisons were assessed according to the treatments of strain, age at photostimulation and diet.

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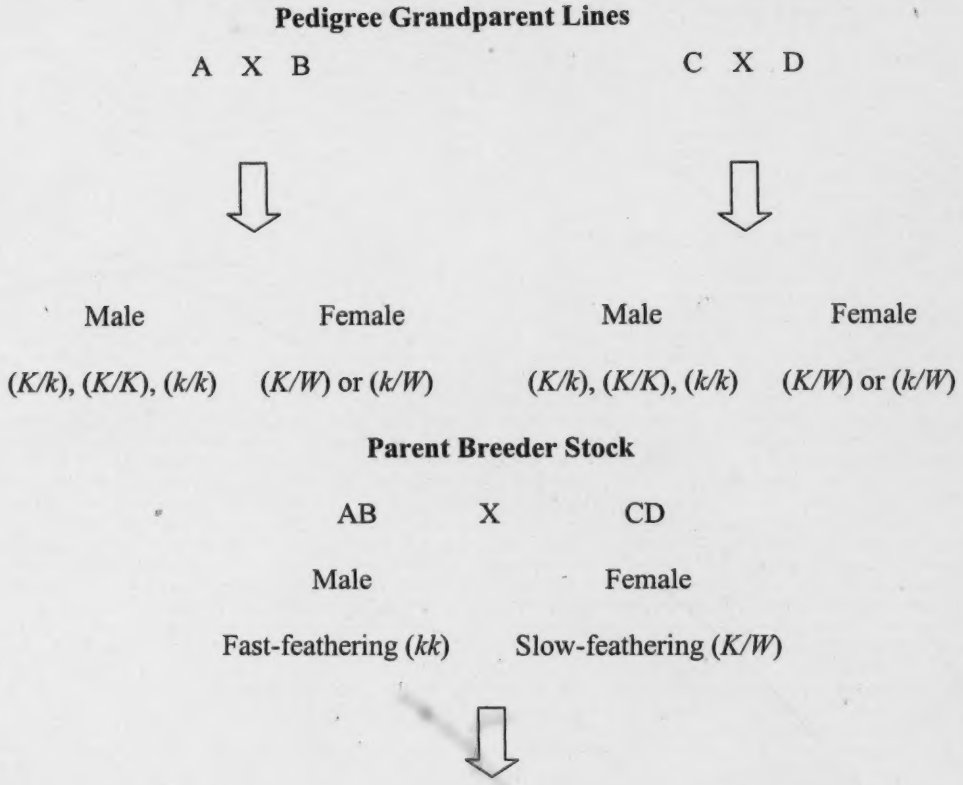

Figure 1-1. Incorporation of the feather-sexing gene into broiler chickens. A similar approach is used for broiler turkeys. The allele *K* is dominant to *k*, and K refers to slow-feathering birds. The *k* allele refers to fast-feathering birds.

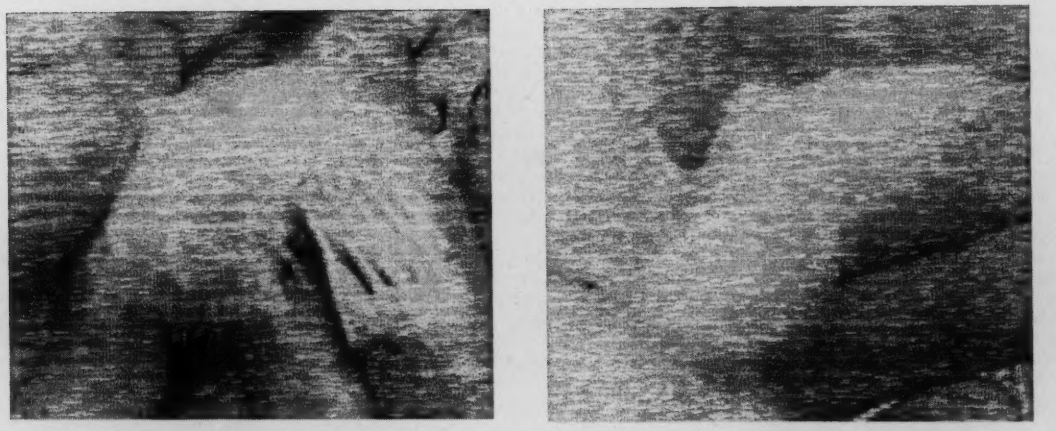

Figure 1-2. Depiction of differences in wing feather development in female day-old poults used in this trial. The fast-feathering poult is shown on the left, and the slow-feathering poult is shown on the right. Note the differences in primary and secondary wing feather development for each. In the broiler chicken industry, the commerical feather-sexable female broiler is fast-feathering, and the male broiler is slow-feathering.

2.0 EFFECTS OF NUTRIENT DENSITY ON GROWTH AND CARCASS TRAITS IN FAST- AND SLOW-FEATHERING TURKEY POULTS

2.1 INTRODUCTION

Sex-separate rearing of birds is commonly practiced in commercial poultry production to optimize feed efficiency and marketing of males and females at the optimum respective body weights (Merkley and Lowe, 1988). Rearing sexes separately may contribute to increased BW uniformity as nutrient and stocking density can be adjusted for faster-growing and more efficient males (Veerapen and Driver, 1999). This practice is most effective when applied from hatching. Commercial poultry can be vent-sexed at the time of hatch by everting and examining the inner vent morphology. Vent-sexing requires handling by trained personnel, resulting in increased production costs (Veerapen and Driver, 1999). This handling increases exposure to exogenous pathogens, causing further stress. Immune responses may result in reduced growth during the rearing period (Korver et al., 1998). Sexing errors may occur as well. Autosexing based on feather color can also be used. However, the pigment from dark-colored feathers in these strains can cause epidermal blemishes at processing, which reduces carcass acceptability to most North American consumers. Feather sexing based on wing feather development at hatch is commonly used in chicken production because it is faster, cheaper and less stressful for chicks than vent-sexing (Harris et al., 1984).

The gene used for feather sexing chickens based on wing feather development (designated as K^{+}) is genetically dominant and sex-linked. This gene has been characterized by Serebrovsky (1922) and Warren (1925). Male broiler chickens with this gene have reduced primary and secondary feather development when compared to

females and are therefore easily distinguishable at hatching. Back feather cover as determined by visual assessment and overall back feather length was lower in male slow-feathering (SF) broiler chickens from 17 d to 31 d of age (McDougald and Keshavarz, 1984). Lack of feather cover can result in bare patches of skin, leaving the skin susceptible to scratching and breakage. This weakening of the skin's barrier may contribute to diseases such as cellulitis (Elfadil et al., 1996). Decreased feather cover can result in increased metabolic requirements as thermal insulation is decreased. This has been observed in chicks that were artificially de-feathered or lacking in feathers due to genetics (Wekstein and Zolman, 1970; Prijono, 1991; Özkan et al., 2002). Some studies report no difference in growth due to genetic feathering type (Hurry and Nordskog, 1953; Saeki and Katsuragi, 1961; Lowe et al., 1965). Others have reported that better growth is seen in birds with normal feather cover (Warren and Payne, 1945; Plumart and Mueller, 1954; Asmundson and Abbott, 1961; Wekstein and Zolman, 1970). Overall, SF birds may have differing proportions of feathers and muscle (both of which are composed primarily of protein) compared to birds with normal feather cover. Therefore, they may respond uniquely to differences in protein intake.

A sex-linked gene for slow feathering was recently incorporated into a commercial line of Large White turkeys. Successful development of feather-sexable poult lines would benefit the turkey industry by reducing sexing errors and poult stress. Because heavy toms are marketed at different ages than hens and turkey broilers, feather sexing could also reduce costs by increasing uniformity of feeding on-farm and processing at the plant. The objective of the current research was to characterize the current performance of these SF birds. Responses of SF birds, such as growth rate,

carcass morphology and feather cover, to increased nutrient density as compared to fast-feathering (FF) commercial birds were also studied.

2.2 MATERIALS AND METHODS

Day-old poults were processed and shipped from Hybrid Turkeys (Kitchener, ON) to research facilities at the Alberta Poultry Research Centre (Edmonton, AB). A total of 432 SF and 432 FF poults were randomly distributed to one of 16 floor pens per strain in a light-tight facility (n=~50 per pen). The birds were raised according to breeder recommendations. Each strain was fed either a control diet (CON), or a high nutrient density diet (HIGH). The CON diet was formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels[1]. The HIGH diet was formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet. There were slight differences in analyzed protein levels compared to the formulated levels, but the HIGH diet was always at least 8% higher in protein. The diets were fed as a starter (1) from 0 to 14 d of age, a starter (2) from 15 to 28 d, a grower (1) from 29 to 56 d of age, a grower (2) from 57 to 91 d, and a holding diet from 92 to 198 d of age (Table 2-1). Feed and water were provided ad libitum throughout rearing. The temperature of the barn was maintained at 32 C until 14 d of age, after which temperature was decreased at a rate of 2 C every week until barn temperature reached approximately 15 to 17 C. Feed consumption was recorded weekly until 28 d of age, and then biweekly until 198 d of age. At both 42 d and 84 d, 96 pre-assigned birds were processed. Birds were killed by cervical dislocation and individually weighed. External measurements, taken after cervical dislocation, included shank length, keel length,

[1] Hybrid Grade Maker Breeder Management Guide, Hybrid Turkeys, Kitchener, ON

thoracic circumference and thoracic width. Using a vernier caliper, shank length was determined by measuring the length of the tibiotarsus (from the top of the hock joint to the bottom of the footpad), and keel length was determined by measuring the distance from the hypocleido-clavical joint to the caudal end of the sternum. Thoracic width was determined using vernier calipers placed under the birds' wings, 2.5-cm below the clavicle bones at approximately the widest point on the chest. Thoracic circumference was measured by wrapping a flexible measuring tape snugly under the wings around the approximate widest point of the chest cavity, joining up at the hypocleido-clavical joint. Internal measurements included weights of pectoralis major (P. major), pectoralis minor (P. minor), liver, and fatpad. Total breast weight was calculated as the sum of the weights of the pectoralis major and pectoralis minor.

The area and thickness of the dissected P. major were measured using the Northern Exposure® digital image analysis system[2]. These data were collected at 42 d and 84 d to objectively characterize breast muscle morphology and uniformity. The P. major was placed on a clean, white surface and peripheral fat and tissue was removed. A digital image was then recorded and measurements obtained using the image analysis software to compare the conformation as well as the uniformity of the P. major (Figure 2-1). Measurements included total area; whole breast length (lines 1 and 2); center length (line 3); horizontal length at the midpoint (line 4); and horizontal length at the widest point (line 5; Figure 2-1). Two 1-cm wide cross-sections were then cut from the P. major using a double-bladed scalpel. The first cross-section was taken from the top of the anatomical left shoulder diagonally down to the posterior end of the P. major (Figure 2-2A). This was then turned flat and the widest (line 6), middle (line 7), thinnest (line 8) and length

(line 9) measurements of the section were taken. This was used to describe the conformation of the P. major muscle from the top of the breast, through the widest part across the breast, down to the posterior end of the P. major to the thinnest part of the hypocleido-clavical joint to the caudal end of the sternum. Thoracic width was determined using vernier calipers placed under the birds' wings, 2.5-cm below the clavicle bones at approximately the widest point on the chest. Thoracic circumference was measured by wrapping a flexible measuring tape snugly under the wings around the approximate widest point of the chest cavity, joining up at the hypocleido-clavical joint. Internal measurements included weights of the pectoralis major (P. major), pectoralis minor (P. minor), liver, and fatpad. Total breast weight was calculated as the sum of the pectoralis major and pectoralis minor weights.

The area and thickness of the dissected P. major were measured using the Northern Exposure® digital image analysis system. These data were collected at 42 d and 84 d to objectively characterize breast muscle morphology and uniformity. The P. major was placed on a clean, white surface and peripheral fat and tissue was removed. A digital image was then recorded and measurements obtained using the image analysis software to compare the conformation as well as the uniformity of the P. major (Figure 2-1). Measurements included total area; whole breast length (lines 1 and 2); center length (line 3); horizontal length at the midpoint (line 4); and horizontal length at the widest point (line 5). Two 1-cm wide cross-sections were then cut from the P. major using a double-bladed scalpel. The first cross-section was taken from the top of the anatomical left shoulder diagonally down to the posterior end of the P. major (Figure 2-A). This was then turned flat and the widest (line 6), middle (line 7), thinnest (line 8) and length (line 9)

[2] Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

measurements of the section were taken. This was used to describe the conformation of the P. major muscle from the top of the breast, through the widest part across the breast, down to the posterior end of the P. major to the thinnest part of the breast. A second cross section was taken at the widest part of the contralateral side of the P. major, starting in a perpendicular manner to where the P. major was attached to the sternum, and ending at the edge of the breast (Figure 2-2B). The length (line 10) and widest (line 11) section of this slice was digitally measured, corresponding to the breast conformation at the middle portion of the P. major.

Feather score was assessed by the same individual at 32 d, 56 d and 98 d using a six-point scale (Figures 2-3; 2-4). Back feather cover of SF and FF poults was assessed using a scoring range of 1 to 6. Feather cover was judged based on the degree of feathering from the base of the neck to the pygostyle of the individual bird. A score of 1 indicated that yellow down was present on the back, with no initial feather development. Two parallel lines of initial feather development on the back with no feathers in the middle of these lines resulted in a score of 2. A thin "V" shape of feathers that extended halfway down the back was given a score of 3. A wider, thicker "V" shape of feather growth extending three-quarters to the full length of the back indicated a score of 4. Fuller feather cover on the back relative to the lower scores indicated a score of 5. Complete back feather cover resulted in a feather score of 6.

The effects of diet and strain and their interaction on the parameters measured were assessed by two-way analysis of variance using the General Linear Model (GLM) procedure of SAS® (SAS Institute, Inc. 1996). Following a significant F-test ($P < 0.05$), differences between means were assessed using the PDIFF t-test procedure of SAS®

(SAS Institute, Inc. 1996). Unless otherwise stated, significance was assessed at the $P < 0.05$ level. The experimental protocol followed the *Guide to the Care and Use of Experimental Animals* (Canadian Council on Animal Care, 1984) and was approved by the Animal Policy and Welfare Committee of the Faculty of Agriculture, Forestry and Home Economics of the University of Alberta.

2.3 RESULTS AND DISCUSSION

Body weight

Strain significantly affected BW from 11 d to 198 d as FF poults were heavier than SF poults throughout rearing (Table 2-2). This difference reached a maximum after 154 d, as FF birds were approximately 0.8 kg heavier than SF birds. Past research reveals inconsistent results when comparing BW of FF and SF chickens. Differences in BW between SF and FF strains and within sexes were noted by Lowe and Merkley (1986), Dunnington and Siegel (1986a) and by Özkan et al. (2002). Comparisons of SF and FF broiler chickens (Ajang et al. 1993) and parent stock chickens (Katanbaf et al., 1989a) revealed no differences in BW between strains. Differences in BW in FF and SF chickens may be due to rapid early feather growth resulting in less available energy for other metabolic processes. However, increased feed efficiency from improved insulation of early feather growth may counteract this effect (Hutt, 1949; Dunnington and Siegel, 1986b). As well, genetics have direct effects on performance-related traits such as growth rate (Hutt, 1949; Lowe and Merkley, 1986; Ajang et al., 1993). Differences in the background genome due to genetic selection over time may have affected results in previous trials (Chambers et al., 1993). Numerous genes, nutrition, and the environment to which the birds are exposed all affect growth rate in poultry. The variable results

described above demonstrate that the SF gene may not be the sole reason for depressed growth in birds carrying this gene. Environmental effects as well as associated genes with pleiotropic effects are likely acting with the SF gene to produce varied results in SF chickens and turkeys.

Increased diet density increased BW in both strains of poults from 4 d to 198 d. This was also the case in broiler chickens and broiler breeder pullets (Merkley and Lowe, 1986; Yaissle and Lilburn, 1998). The maximum difference in BW due to dietary treatment was at 84 d for both strains, and this difference was 16.9% in FF birds and 7.9% in SF birds. There was an interaction of strain and diet from 4 d to 198 d, in which the HIGH treatment increased BW to a greater extent in the FF than in the SF birds. An increase in BW was an expected response because the diets were formulated to breeder recommendations, which are lower in overall nutrient levels compared to broiler diets. Because the SF had less feather cover than FF birds, their maintenance energy and nutrient requirements may have been increased. It is not possible to state this with certainty, as the environmental temperatures did not reach levels below the thermoneutral zone for turkeys. However, past research has shown that feather cover is important to thermal resistance in birds. Herreid and Kessel (1976) observed significantly increased sensible heat transfer by conductance in defeathered birds compared to birds with full feather cover. There is a generally positive relationship between total feather weight and thermal resistance, which is associated with decreased heat production (Prijono, 1991). If thermal resistance is decreased and heat production is increased, there may be a subsequent positive relationship with overall maintenance requirements. Merkley and

Lowe (1986) found no interaction of strain and diet in FF and SF broiler chickens, and attributed this to insufficient divergence of dietary protein levels in their experiments.

Feed conversion

Feed conversion efficiency was not affected by strain. This has also been observed in FF and SF broiler chickens (Lowe and Merkley, 1986; Ajang et al., 1993). Poults with the SF gene had decreased BW (Table 2-2) but also had increased breast muscle weight (Table 2-5) compared to FF poults. Although organisms with greater body size are expected to have higher maintenance energy requirements, differences in energy costs for deposition of lean and fat tissue, and other metabolic processes masked the expected difference in feed conversion ratio. In broiler chickens selected for leanness (Leclercq and Guy, 1991) or feed efficiency (Buyse et al., 1998), differences in energy metabolism were observed as more efficient birds used retained energy for protein deposition instead of carcass fat. The levels of carcass lipid and protein in the two strains were not measured in this trial, but it has been suggested that SF birds have a different approach to nutrient partitioning compared to FF birds (Ajang et al., 1993).

At 70 d and 84 d, poults fed the CON diet were significantly less efficient than poults fed the HIGH diet (Table 2-3). This is likely due to the less dense breeder formulation of the control diet (compared to the HIGH diet or a commerical meat-type diet formulation) being fed during a period of relatively rapid growth. From 140 to 198 d, feeding the CON diet resulted in better feed conversion efficiency than feeding the HIGH diet. This is likely because the protein level was above the birds' protein requirement, and energy was expended to deaminate excess protein. Varied effects of increasing dietary protein content on feed conversion efficiency have been reported previously (Lowe and

Merkley, 1986; Granot et al., 1991; Ajang et al., 1993). Feed conversion can be greatly affected by many factors including strain, environment, feed type, feed intake, bird age, and immune response. Overall, the feed conversion efficiency of the flock was comparable to industry standards for breeders.[3]

Feather score

Feather cover as indicated by feather score was significantly lower in SF poults compared to FF poults at every age (Table 2-4). No SF birds achieved a feather score of 6, or full feather cover. Decreased feather score (Lowe and Merkley, 1986; Dunnington and Siegel, 1986b) and feather weight (Özkan et al., 2002) was reported in SF broiler chickens.

Increased nutrient density significantly increased feather scores of SF poults at 32 d and 56 d, but not at 98 d. Feeding a greater amount of dietary protein to SF poults resulted in more nutrients being partitioned toward feather growth at 32 d and 56 d. At 98 d and beyond, initial feather development was nearly complete, and the increased level of protein provided in the HIGH diet may have been utilized for breast muscle deposition. Dunnington and Siegel (1986a) found no difference in absolute or % feather weight relative to BW in older SF and FF broiler chickens at 147 d and 196 d of age.

Rate of BW gain is generally more rapid early in life (Becker and Berg, 1959). Sheridan and McDonald (1963) stated that in broiler chickens, a competition between muscle and feather growth was apparent during this period of rapid growth. Dunnington and Siegel (1986b) found that rate of feathering proceeded at a slower rate than BW gain from 147 d to 196 d in both SF and FF broilers. This may indicate differential nutrient partitioning depending on the age of the bird. Genetic differences in protein utilization

[3]Hybrid Grade Maker Breeder Management Guide, Hybrid Turkeys, Kitchener, ON

have been studied in detail, including effect of dietary protein content (Leclercq, 1983), sulphur amino acid (SAA) utilization (Leclercq et al., 1993) and non-essential amino acid (NEAA) content (Alleman et al., 2000) in genetically lean and fat broiler chickens. Briefly, lean birds were more likely to have reduced growth in response to lower CP and SAA levels, and required increased levels CP, (including SAA and NEAA) because of decreased feed consumption and increased feather weight gain compared to fat birds. Lean birds also had greater efficiency of protein utilization compared to fat birds. Leclercq and Guy (1991) attributed these results to genetic differences in amino acid utilization.

Carcass morphology

The total breast weight, P. major weight and P. minor weight were consistently greater at 42 d by 10.0%, 11.5% and 13.3% respectively in SF birds (Table 2-5). As well, % breast muscle was also increased in SF at 42 d. Specifically, increases in mean % total breast weight (2.6%, 3.2%), % P. major weight (2.0%, 2.6%), % pectoralis minor (P. minor) weight (0.6%, 0.7%) were observed in SF birds at 42 d and 84 d respectively compared to FF birds. Liver weight relative to BW was increased (0.12%) in SF poults compared to FF poults at 42 d. Ajang et al. (1993) also found that SF broiler chickens had less carcass fat, more carcass protein and similar BW and liver weight to 42 d compared to FF birds. They suggested that increased heat production measured through calorimetry in SF chickens from increased carcass protein levels and subsequent protein turnover would make up for some of the heat loss incurred from less feather cover. Merkley and Lowe (1988) reported an increase in breast weight and an increase in absolute liver weight in 53 d-old male SF broiler chickens.

At 84 d, FF birds were 2.9% heavier than SF birds (Table 2-6). The total breast weight, P. major weight and P. minor weight were increased at 84 d by approximately 10.0%, 11.5% and 14.4% respectively in SF birds. Mean % total breast weight (3.2%), % P. major weight (2.6%), % pectoralis minor (P. minor) weight (0.7%) were observed in SF birds at 84 d compared to FF birds. Birds with genetically absent or reduced feather growth can have increased breast muscle growth (Somes and Johnson, 1982; Somes and Wiedenheft, 1982; Ajang et al., 1993) under appropriate environmental conditions. Merkley and Lowe (1988) found this result in male SF broiler chickens compared to FF birds, but not in females. These studies are in contrast to the findings of others (Katanbaf et al., 1988; Katanbaf et al., 1989b) who found no difference in breast muscle growth between SF and FF parent stock chickens.

Increased nutrient density significantly increased BW (8.0%) and keel (3.9%) length of processed birds at 42 d (Table 2-5). Breast muscle weight was greater in birds fed the HIGH diet at 42 d. This is associated with increased thoracic circumference (3.5%) and width (7.4%) measurements at 42 d. The HIGH diet increased absolute weights of the total breast, P. major and P. minor by 7.1%, 6.8% and 8.5 % respectively, as well as shank length (2.4%) at 42 d. There was an increase in absolute and % weight of the abdominal fatpad relative to BW at 42 d in poults fed the HIGH diet compared to poults fed the CON diet. Liver weight as a percentage of BW was significantly decreased in birds fed the HIGH diet at 42 d by 0.11%.

Increased nutrient density significantly increased BW (9.8%) and keel (4.1%) length of processed birds at 84 d respectively (Table 2-6). At 84 d, the HIGH diet resulted in increased total breast weight (18.7%), P. major weight (19.1%), P. minor weight

(17.8%), as well as % weights of those tissues relative to BW. This is associated with increased thoracic circumference (5.1%) and width (8.9%) measurements at 84 d. Feeding the HIGH diet did not affect abdominal fatpad weight at 84 d compared to feeding the CON diet. Liver weight as a percentage of BW was significantly decreased in birds fed the HIGH diet at 84 d by 0.29%.

Merkley and Lowe (1988) reported similar findings regarding BW and muscle growth. Lilburn and Myers-Miller (1990) also reported increased P. major weight, but not increased tibia length in 13 wk and 18 wk feed-restricted broiler breeder pullets fed a broiler starter compared to birds fed a broiler breeder pullet grower. The results of the current trial are in contrast to previous research in which lower abdominal fatpad weights were reported in chickens with increased nutrient intake (Lilburn and Myers-Miller, 1990; Smith et al., 1998; Özkan et al., 2002). This contrast of the present results with previous trials may be due to differences in dietary energy to protein ratios, as well as actual feed intake.

Overall, a higher plane of nutrition increased poult body reserves as shown by increases in BW, muscle and skeletal growth. The CON diet was formulated based on breeder requirements, so the HIGH diet could be considered closer to nutrient levels normally fed to commercial meat-type birds. Feeding the HIGH diet therefore provided sufficient protein for poults to maximize their genetic ability for muscle growth. The increased fatpad weight in poults fed the HIGH diet at 42 d indicates that extra energy was being stored as fat. At 84 d, breast muscle deposition continued to be higher in poults fed the HIGH diet compared to those fed the CON diet as at 42 d. However, fatpad was not increased by feeding the HIGH diet at 84 d, demonstrating that extra energy was

likely being used for the process of muscle deposition instead of being stored as fat at this time. When considering the implications of these results for the subsequent reproductive period, it is not possible to conclude that increased nutrient reserves during rearing alone could completely address decreased reproductive efficiency in SF turkeys, especially when the exact genotypic expressions through the phenotype for these birds is not known. However, increasing nutrient density did have positive effects during rearing, indicating that metabolism of young SF turkeys can be manipulated to some extent using this approach.

Breast muscle morphology

At 42 d, SF birds had 5.1% larger P. major area measurements compared to FF birds (Table 2-7). Breast width measurements at the middle (line 4) and widest (line 5; Figure 2-1) points were increased by 4.5% and 3.4% respectively in SF birds compared to FF birds. The breast muscle was also thicker (11.6%) in SF birds (line 11; Figure 2-2B) compared to breast muscle of FF birds. Overall, increased breast muscle weight in SF poults compared FF poults at 42 d (Table 2-5) is consistent with breast morphology data. This increase was accounted for solely by muscle thickness, and not muscle area or width. The FF poults may have been catching up in terms of muscle development as seen with processing BW (Table 2-5). The SF birds, having fewer feathers, partitioned fewer amino acids to keratin synthesis, making them available for the formation of other body proteins (Ajang et al., 1993).

At 84 d, SF birds had increased internal muscle thickness at the top (line 6; Figure 2-2A) and middle (line 7; Figure 2-2A, and line 11; Figure 2-2B) of the P. major by 5.9%, 11.0% and 9.5% respectively compared to FF birds (Table 2-8). This increase in

breast thickness corresponded to the increased average breast weight seen in SF birds at 84 d (Table 2-6).

Increased diet density resulted in greater P. major size at 42 d in terms of area by 5.6%, whole breast length (lines 1 and 2) by 2.9%, and width (line 4; Figure 2-1) by 3.0% (Table 2-7). Length from the sternum to the breast edge (line 10; Figure 2-2B) was 5.3% increased at 42 d in birds fed the HIGH diet compared to those fed the CON diet. The larger 42-d external thoracic circumference and width measurements (Table 2-5) in birds fed the HIGH diet support these breast muscle measurement results. Breast thickness was not affected by diet density alone at 42 d as determined by the slice measurements. Feeding the HIGH diet increased P. major area, length across the middle (line 4) and widest (line 5; Figure 2-1) points, and internal muscle thickness near the bottom of the muscle (line 8; Figure 2-2A) to a larger extent in FF birds compared to SF birds at 42 d. Poults with the SF phenotype had thicker breast muscle in the top portion of the P. major than poults with the FF phenotype, indicating that FF poults had more uniform muscle deposition throughout the breast at 84 d.

At 84 d, increasing diet density significantly increased nearly all measurements related to the P. major, except thickness near the bottom of the muscle (line 8; Figure 2-2A). This coincided with the positive effects of increased nutrient density on muscle growth in 84-d birds fed the HIGH diet (Table 2-6). Increased nutrient density increased P. major measurements to a greater extent at 84 d than at 42 d. It may be that by 84 d, initial feather growth was nearly complete and no longer a major source of competition for dietary nutrients. Keel length (line 3; Figure 2-1) was increased to a greater extent by

diet density in FF birds (7.5%) compared to SF birds (1.1%). The SF birds, while maintaining muscle growth, showed reduced growth frame growth relative to FF birds.

Overall, the SF poults expressed different BW, muscle growth and feather cover compared to FF poults. The SF poults had reduced growth compared to commercial birds after 112 d in this trial, however, breast muscle as a proportion of BW was increased in SF birds. Feather cover in SF birds was reduced relative to FF birds, however, this was improved during the period of rapid feather development by increasing nutrient density. A higher plane of nutrition resulted in increased frame size muscle growth for both strains. The HIGH diet was more similar to a diet formulated for meat-type production than the CON diet, and allowed the poults to increase muscle growth. The FF turkeys demonstrated an increased priority for feather protein partitioning while SF birds were genetically inclined to deposit protein as muscle.

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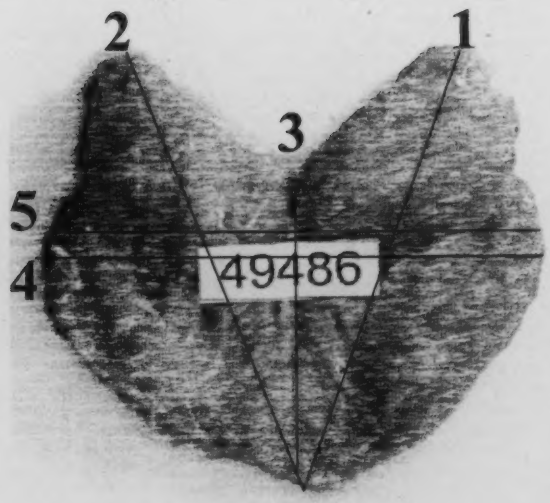

Figure 2-1. Digital[1] measurements[2] of pectoralis major (P. major).

[1] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[2] Whole breast measurements: area = surface area of P. major; line 1 = length from the tip of the anatomical left shoulder diagonally to the posterior end of the breast where P. major was attached to the sternum; line 2 = length from the tip of the anatomical right shoulder diagonally to the posterior end of the breast where P. major was attached to the sternum; line 3 = length corresponding to where P. major was attached to the sternum; line 4 = line corresponding to width at midpoint of breast; line 5 = line corresponding to width at widest point of breast

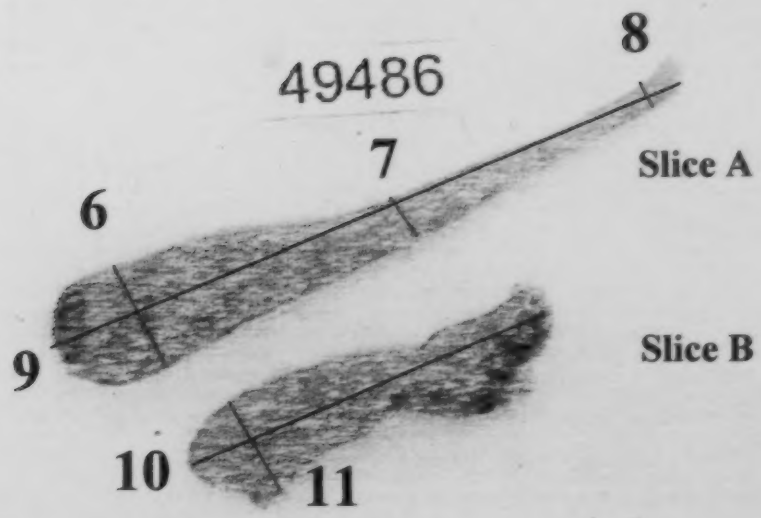

Figure 2-2. Digital[1] measurements[2, 3] from cross-sections of pectoralis major (P. major).

[1] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[2] Slice A measurements: 1-cm wide slice following line 1 of the whole breast. Cross-section of P. major taken using a double-bladed scalpel from the left side of the muscle beginning at the top of the anatomical left shoulder and continuing diagonally towards the posterior end of the breast where the P. major was attached to the sternum, following line 1 of the whole breast. Line 6 = uppermost thickness near the top anatomical left half of the P. major; line 7 = thickness of the muscle at the approximate middle of the anatomical left half of the P. major; line 8 = thickness of the muscle near the bottom of the P. major; line 9 = length of Slice A.

[3] Slice B measurements: 1-cm wide slice following line 4 on the whole breast. Cross-section of P. major taken using a double-bladed scalpel from the anatomical right side of the muscle beginning at where the P. major was attached to the sternum and continuing to the outward edge of the muscle. Line 10 = length of Slice B; line 11 = innermost thickness of muscle, closest to where the P major was attached to the sternum.

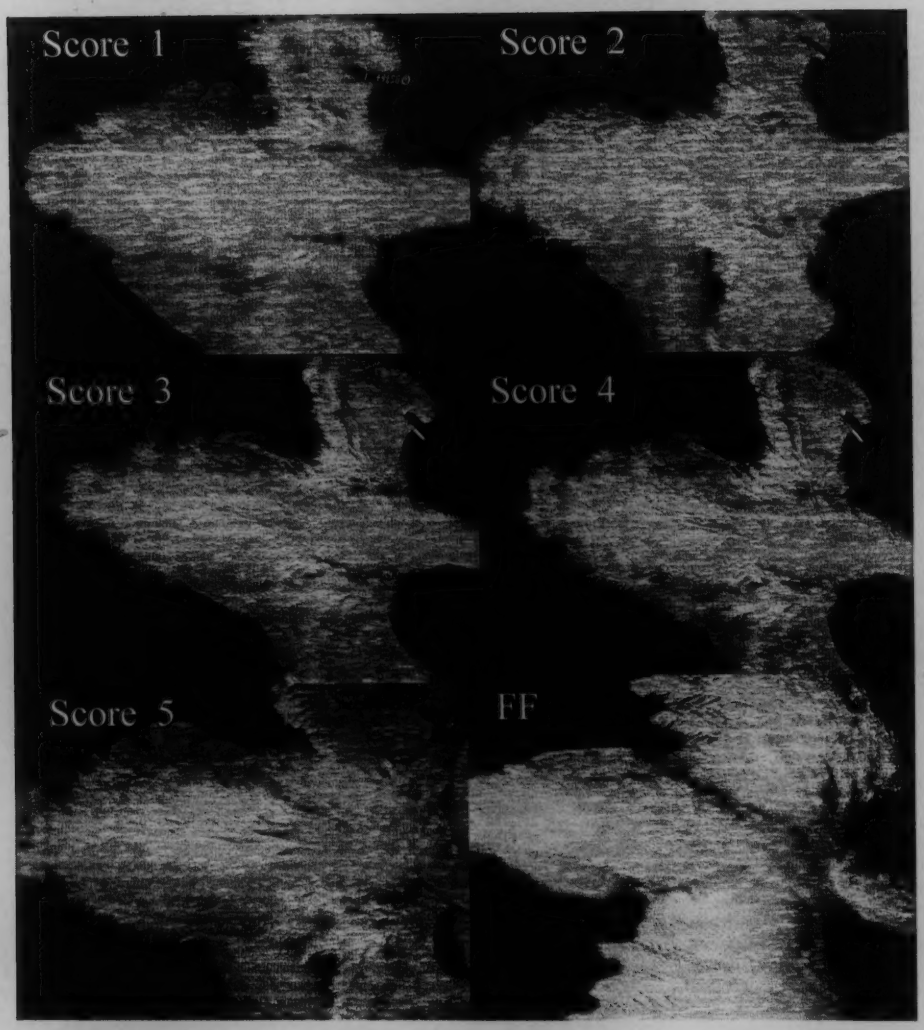

Figure 2-3. Feather scores at 32 d. Shown are scores 1, 2, 3, 4, 5 and 6 (fully-feathered).

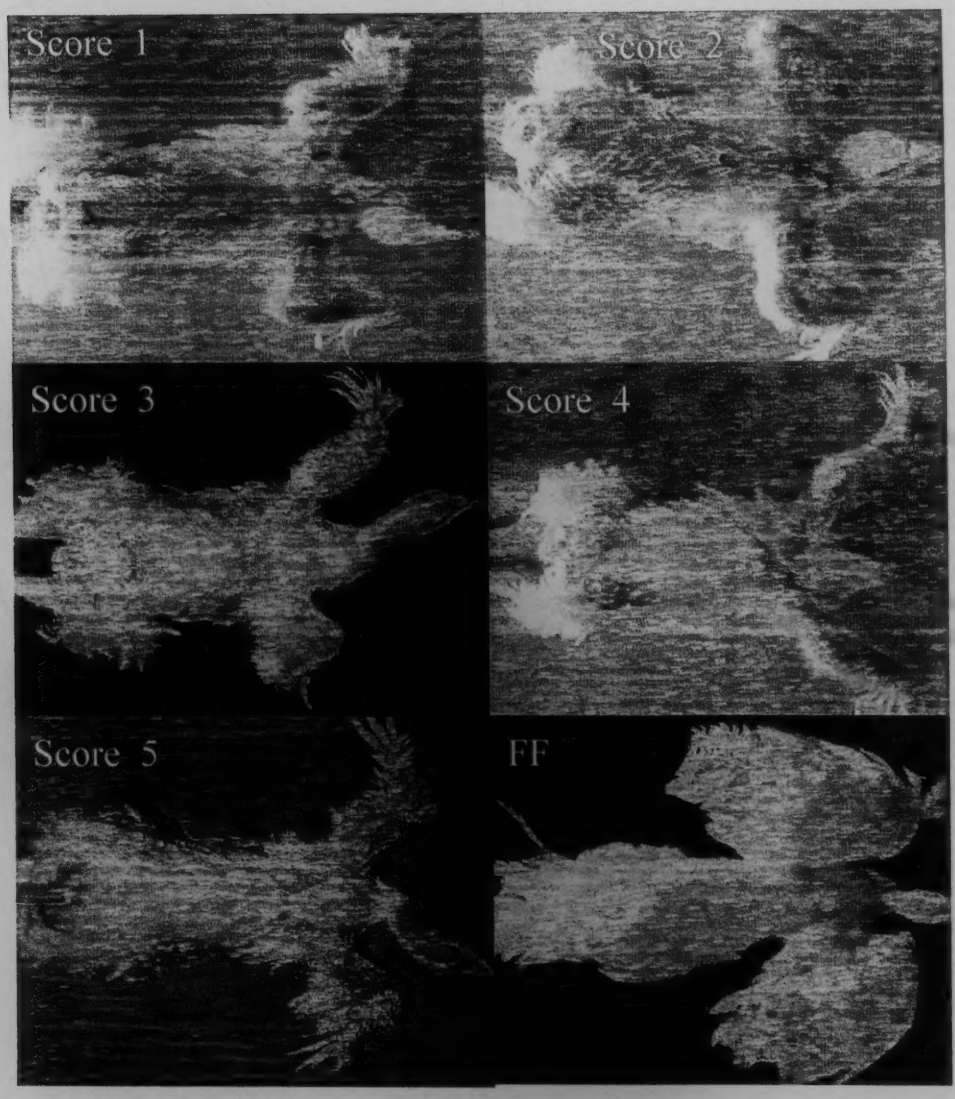

Figure 2-4. Feather scores at 56 d. Shown are scores 1, 2, 3, 4, 5 and 6 (fully-feathered).

Table 2-1. Ingredient and calculated nutrient composition of turkey rations fed from 0 to 198 d of age

Ingredients	Starter 1 (0 to 14 d)		Starter 2 (14 to 28 d)		Grower 1 (28 to 56 d)		Grower 2 (56 to 91 d)		Holding Diet (91 to 196 d)	
	Control	High	Control	High	Control	High	Control	High	Control	High
	g/1000 g									
Ground corn	479.9	352.8	486.0	337.1	418.2	430.1	384.1	497.5	409.6	523.1
Wheat, HRS, ground	...	...	28.8	100.0	250.0	53.9	454.2	35.2	248.3	250.0
Wheat shorts	...	40.5	...	...	...	...	...	...	...	...
Ground oats	...	...	...	...	...	...	...	...	239.1	53.5
Canola meal	10.5	...	...	...	...	...	...	...	...	...
48% soybean meal	444.2	507.9	416.2	460.6	268.3	412.3	102.3	353.5	50.0	115.9
Ground limestone	14.3	15.4	14.5	14.4	15.6	14.9	15.2	14.0	13.5	14.6
Biofos	32.7	34.8	32.9	32.6	28.1	27.7	26.1	25.6	24.7	28.2
Canola oil	...	30.9	3.4	37.6	2.9	43.4	....	57.3	...	...
Choline chloride premix[1]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Hybrid vitamin premix[2]	2.0	2.0	2.0	2.0	1.5	1.5	0.8	0.8	0.8	0.8
Hybrid mineral premix[3]	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8
NaCl	3.8	3.8	3.8	3.8	4.1	4.1	4.1	4.1	5.0	5.0
D,L-methionine	3.0	3.3	2.4	2.7	1.7	2.5	1.7	2.2	0.3	0.5
L-lysine HCl	3.1	2.3	3.0	2.2	2.7	2.6	2.4	2.7	...	...
L-threonine	...	...	...	...	...	...	2.4	0.3	2.0	1.7
Avizyme 1302[4]	...	...	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Amprol	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
Nutrient Composition										
Crude protein (%)[5]	26.1	28.3	24.8	26.7	20.4	24.5	15.5	22.0	12.5	14.5
Crude protein (%)[6]	28.6	31.1	27.3	29.2	24.2	29.4	23.1	26.9	13.7	17.7
ME (Kcal/kg)[5]	2750	2850	2800	2950	2900	3050	3002	3200	2900	2975
Linoleic acid (%)[5]	1.2	1.7	1.3	1.8	1.2	2.1	1.2	2.5	1.4	1.4
Fat (%)[5]	2.3	5.1	2.7	5.7	2.6	6.5	2.4	8.0	3.1	2.8
Fibre (%)[5]	2.9	3.1	2.8	2.8	2.6	2.7	2.4	2.6	4.3	2.8
Calcium (%)[6]	1.6	1.6	1.3	1.4	1.7	1.4	1.3	1.4	1.1	1.2
Available P (%)[5]	0.8	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6
Total P (%)[6]	1.3	1.3	1.2	1.2	1.2	1.1	1.0	1.1	0.9	1.0
Potassium (%)[5]	1.0	1.2	1.0	1.1	0.8	1.0	0.5	0.9	0.4	0.5
Chloride (%)[5]	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Sodium (%)[5]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Methionine (%)[5]	0.71	0.73	0.63	0.72	0.54	0.61	0.42	0.64	0.21	0.32
Met + Cys (%)[5]	1.12	1.22	1.03	1.11	0.84	1.05	0.73	0.91	0.53	0.51
Lysine (%)[5]	1.72	1.81	1.64	1.73	1.22	1.61	0.82	1.47	0.53	0.62
Threonine (%)[5]	1.02	1.11	0.94	1.09	0.73	0.92	0.76	0.91	0.62	0.71
Arginine (%)[5]	1.81	1.92	1.76	1.84	1.23	1.64	0.81	1.48	0.74	0.82

[1] Choline chloride premix provided choline at 100 mg per kilogram of diet

[2] Vitamin premix provided the following per kilogram of diet: vitamin A, 12,000 IU; vitamin D3, 3,000 IU; vitamin K, 2.0 mg; pantothenic acid, 20.0 mg; riboflavin 6.0 mg; folacin, 1.2 mg; niacin, 90.0 mg; thiamine, 3.0 mg; vitamin B12, 0.02 mg, biotin, 0.25 mg; vitamin E, 40 IU.

[3] Mineral premix provided the following in mg per kg of diet: I, 0.5; Mn, 75.0; Cu, 15.0; Zn, 80.0; Se, 0.1; Fe, 100.0.

[4] Danisco Animal Nutrition, Malboro, UK

[5] Calculated nutrient levels.

[6] Analyzed nutrient levels.

Table 2-2. Effect of diet (CON or HIGH)[1] and strain (FF and SF)[2] on BW in turkeys 1 to 198 d of age

	Age (d)																
	1	4	11	21	28	42	56	70	84	98	112	126	140	154	170	184	198
	g					*kg*											
Strain X diet																	
FF X CON	52.1	67.5^{b}	160.2^{c}	309.7^{c}	543.1^{c}	1.15^{c}	2.21^{c}	3.11^{c}	4.09^{c}	4.96^{c}	5.65^{c}	6.60^{b}	7.47^{b}	8.30^{b}	8.90^{b}	9.50^{b}	9.80^{b}
FF X HIGH	52.7	70.3^{a}	178.6^{a}	342.5^{a}	595.8^{a}	1.31^{a}	2.48^{a}	3.72^{a}	4.93^{a}	5.84^{a}	6.68^{a}	7.59^{a}	8.38^{a}	9.00^{a}	9.50^{a}	9.90^{a}	10.30^{a}
SF X CON	52.1	68.9^{b}	163.2^{c}	306.2^{c}	534.4^{c}	1.16^{c}	2.21^{c}	3.18^{c}	4.13^{c}	4.88^{c}	5.56^{c}	6.39^{c}	7.09^{c}	7.80^{c}	8.30^{c}	8.80^{c}	9.10^{c}
SF X HIGH	52.3	68.6^{b}	168.0^{b}	324.3^{b}	568.0^{b}	1.25^{b}	2.32^{b}	3.45^{b}	4.48^{b}	5.25^{b}	5.93^{b}	6.74^{b}	7.41^{b}	8.00^{b}	8.50^{c}	8.90^{c}	9.20^{c}
SEM	3.7	6.0	18.6	34.4	55.8	0.12	0.21	0.31	0.40	0.48	0.55	0.64	0.72	0.76	0.81	0.80	0.84
	P-value																
Sources of variation																	
Strain	NS	NS	0.0158	0.0002	0.0001	0.0050	0.0001	0.0002	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Diet	NS	0.0143	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0021
Interaction	NS	0.0027	0.0001	0.0124	0.0435	0.0001	0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	0.0046	0.0199	NS

[a-c] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

Table 2-3. Effect of diet (CON or HIGH)[1] on feed conversion efficiency in turkeys 14 to 198 d of age

Age (d)	Diet		SEM	*P-value*
	CON	HIGH		
	g feed/g gain			
14	1.93	1.79	0.19	NS
21	2.01	1.91	0.19	NS
28	1.61	1.58	0.21	NS
42	1.94	1.79	0.23	NS
56	2.15	2.04	0.35	NS
70	3.10[a]	2.50[b]	0.36	0.0343
84	3.64[a]	3.06[b]	0.41	0.0337
98	4.51	4.33	0.42	NS
112	5.69	5.56	0.41	NS
126	4.93	5.18	0.49	NS
140	5.79[b]	6.34[a]	0.45	0.0163
154	6.33[b]	7.00[a]	0.51	<0.0001
170	7.61[b]	9.98[a]	0.90	<0.0001
184	8.10[b]	10.65[a]	0.92	<0.0001
198	8.95[b]	11.22[a]	0.98	<0.0001

[a, b] Means within a row with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet

Table 2-4. Effect of diet (CON or HIGH)[1] and strain (FF and SF)[2] on feather score[3] in turkeys 32 to 98 d of age

	Age (d)		
	32	56	98
Strain X diet	*Feather score*		
FF X CON	6.0[a]	6.0[a]	6.0[a]
FF X HIGH	6.0[a]	6.0[a]	6.0[a]
SF X CON	2.9[c]	3.4[c]	4.1[b]
SF X HIGH	3.2[b]	3.7[b]	4.0[b]
SEM	0.1	0.1	0.1
	P-value		
Source of variation			
Strain	0.0001	0.0001	0.0001
Diet	0.0037	0.0289	NS
Interaction	0.0037	0.0289	NS

[a-c] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] Feather score was assessed by the same individual at 32 d, 56 d and 98 d using a six-point scale. Back feather cover of SF and FF poults was assessed using a scoring range of 1 to 6. Feather cover was judged based on the degree of feathering from the base of the neck to the pygostyle of the individual bird. A score of 1 indicated that yellow down was present on the back, with no initial feather development. Two parallel lines of initial feather development on the back with no feathers in the middle of these lines resulted in a score of 2. A thin "V" shape of feathers that extended halfway down the back was given a score of 3. A wider, thicker "V" shape of feather growth extending three-quarters to the full length of the back indicated a score of 4. Fuller feather cover on the back relative to the lower scores indicated a score of 5. Complete back feather cover resulted in a feather score of 6.

Table 2-5. Effect of diet (CON or HIGH)[1] and strain (FF or SF)[2] on turkey carcass morphology at 42 d of age

						Breast muscle parameters									
	BW	Shank length	Keel length	Thoracic circumf.	Thoracic width[3]	Breast Weight[4]		Pectoralis major weight		Pectoralis minor weight		Abdominal fatpad weight		Liver Weight	
	(g)	(mm)	(mm)	(mm)	(mm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
Strain															
FF	1,235.4	102.5	92.5	289.4	71.4	213.8^{b}	17.3^{b}	166.7^{b}	13.5^{b}	47.1^{b}	3.83^{b}	0.58	0.045	21.67	1.76^{b}
SF	1,199.1	101.4	93.0	287.9	72.1	237.9^{a}	19.9^{a}	185.3^{a}	15.5^{a}	52.7^{a}	4.42^{a}	0.71	0.059	22.47	1.88^{a}
SEM	20.7	0.6	0.7	2.0	0.9	3.9	0.1	3.1	0.1	0.9	0.03	0.07	0.006	0.44	0.02
Diet															
CON	1,167.2^{b}	100.7^{b}	90.9^{b}	283.5^{b}	69.0^{b}	217.5^{b}	18.6	169.8^{b}	14.5	47.7^{b}	4.12	0.50^{b}	0.042^{b}	21.85	1.88^{a}
HIGH	1,267.3^{a}	103.2^{a}	94.6^{a}	293.8^{a}	74.5^{a}	234.2^{a}	18.6	182.2^{a}	14.4	52.1^{a}	4.14	0.80^{a}	0.063^{a}	22.29	1.77^{b}
SEM	20.6	0.6	0.7	2.0	0.9	3.9	0.1	3.1	0.1	0.9	0.03	0.07	0.006	0.44	0.02
Strain X diet															
FF X CON	1,161.6	101.0	89.9	280.4^{c}	67.4	201.0	17.3	157.3	13.6	43.7	3.82	0.44	0.037	21.50	1.86^{a}
FF X HIGH	1,309.2	104.0	95.0	298.3^{a}	75.4	226.6	17.3	176.1	13.5	50.5	3.91	0.73	0.054	21.85	1.67^{b}
SF X CON	1,172.9	100.5	91.9	286.6^{bc}	70.6	234.0	19.9	182.3	15.5	51.7	4.41	0.55	0.047	22.21	1.89^{a}
SF X HIGH	1,225.3	102.4	94.2	289.3^{ab}	73.6	241.9	19.8	188.2	15.4	53.6	4.43	0.88	0.072	22.73	1.86^{a}
SEM	29.7	0.9	1.0	2.8	1.3	5.6	0.2	4.5	0.2	1.3	0.03	0.10	0.009	0.60	0.03
	P-value														
Sources of variation															
Strain	NS	NS	NS	NS	NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	NS	NS	NS	0.0004
Diet	0.0012	0.0073	0.0004	0.0004	0.0001	0.0033	NS	0.0064	NS	0.0011	NS	0.0043	0.0113	NS	0.0006
Interaction	NS	NS	NS	0.0078	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0183

[a-d] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] Measurement taken across the breast of the bird above the top of the sternum

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 2-6. Effect of diet (CON or HIGH)[1] and strain (FF or SF)[2] on turkey carcass morphology at 84 d of age

	BW	Shank length	Keel length	Thoracic circumf.	Thoracic width[3]	Breast muscle parameters: Breast weight[4]		Pectoralis major weight		Pectoralis minor weight		Abdominal fatpad weight		Liver Weight	
	(g)	(mm)	(mm)	(mm)	(mm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
Strain															
FF	4,362.7[a]	141.1	140.2	469.8	119.8	845.5[b]	19.3[b]	658.5[b]	15.0[b]	187.0[b]	4.33[b]	27.19	0.62	59.44	1.38
SF	4,237.9[b]	138.5	140.5	464.3	121.2	955.2[a]	22.5[a]	744.9[a]	17.6[a]	211.2[a]	5.06[a]	25.04	0.58	57.87	1.37
SEM	37.0	1.0	0.9	3.2	1.1	13.2	0.2	11.9	0.2	2.5	0.04	2.07	0.05	1.46	0.03
Diet															
CON	4,077.7[b]	140.0	137.4[b]	454.8[b]	114.9[b]	807.5[b]	19.8[b]	627.5[b]	15.4[b]	179.7[b]	4.42[b]	26.12	0.62	61.84[a]	1.52[a]
HIGH	4,523.0[a]	139.7	143.3[a]	479.3[a]	126.1[a]	993.3[a]	22.0[a]	775.9[a]	17.2[a]	218.6[a]	4.87[a]	26.11	0.57	55.47[b]	1.23[b]
SEM	36.6	1.0	0.9	3.1	1.1	13.1	0.2	11.7	0.2	2.5	0.04	2.05	0.05	1.45	0.03
Strain X diet															
FF X CON	4,032.8[c]	141.5	135.8[c]	452.9	112.3	732.3[d]	18.2	570.3	14.2	161.9[d]	4.01	28.03	0.67	63.98[a]	1.58[a]
FF X HIGH	4,692.5[a]	140.8	144.6[a]	486.6	127.3	958.8[b]	20.4	746.7	15.9	212.1[b]	4.53	26.35	0.56	54.91[b]	1.17[d]
SF X CON	4,122.5[c]	138.6	138.9[b]	456.7	117.4	882.8[c]	21.5	684.7	16.7	197.4[c]	4.86	24.20	0.57	59.70[a]	1.45[b]
SF X HIGH	4,353.4[b]	138.5	142.0[a]	471.9	125.0	1027.7[a]	23.7	805.0	18.5	225.1[a]	5.21	25.87	0.61	56.04[b]	1.29[c]
SEM	55.9	1.4	1.3	4.8	2.6	19.9	0.3	17.9	0.3	3.7	0.04	2.62	0.06	1.78	0.03
P-value															
Sources of variation															
Strain	0.0283	NS	NS	NS	NS	0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001	NS	NS	NS	NS
Diet	<0.0001	NS	0.0008	0.0002	0.0006	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	NS	NS	0.0093	<0.0001
Interaction	0.0017	NS	0.0214	NS	NS	0.0415	NS	NS	NS	0.0052	NS	NS	NS	NS	0.0131

[a-d] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] Measurement taken across the breast of the bird above the top of the sternum

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 2-7. Effect of diet (CON or HIGH)[1] and strain (FF or SF)[2] on breast muscle conformation as determined by digital image analysis[3] in turkeys at 42 d of age

	Whole breast[4]						Slice A[5]				Slice B[6]	
	Area (cm2)	Length from right side (cm)	Length from left side (cm)	Keel (cm)	Middle (cm)	Widest (cm)	Length (cm)	Widest (cm)	Middle (cm)	Thinnest (cm)	Length (cm)	Widest (cm)
Strain												
FF	130.71^{b}	13.68	13.75	9.38	14.10^{b}	14.53^{b}	16.08	3.04	1.35	0.68	9.17	2.45^{b}
SF	137.67^{a}	13.72	13.79	9.56	14.76^{a}	15.04^{a}	16.39	3.15	1.40	0.68	9.17	2.77^{a}
SEM	2.13	0.14	0.13	0.09	0.15	0.15	0.22	0.06	0.03	0.02	0.16	0.05
Diet												
CON	130.35^{b}	13.50^{b}	13.57^{b}	9.35	14.25	14.56^{b}	16.00	3.02	1.34	0.68	8.92^{b}	2.55
HIGH	138.04^{a}	13.90^{a}	13.97^{a}	9.59	14.61	15.01^{a}	16.47	3.18	1.41	0.69	9.42^{a}	2.67
SEM	2.13	0.14	0.13	0.092	0.15	0.15	0.22	0.06	0.04	0.02	0.16	0.05
Strain X diet												
FF X CON	122.90^{b}	13.36	13.37	9.15	13.66^{b}	14.03^{b}	15.79	2.92	1.35	0.64^{b}	8.77	2.45
FF X HIGH	138.60^{a}	14.01	14.13	9.60	14.55^{a}	15.03^{a}	16.37	3.17	1.35	0.72^{a}	9.56	2.45
SF X CON	137.80^{a}	13.65	13.77	9.55	14.84^{a}	15.10^{a}	16.21	3.12	1.34	0.71^{a}	9.06	2.65
SF X HIGH	137.50^{a}	13.79	13.82	9.58	14.68^{a}	14.99^{a}	16.58	3.19	1.46	0.65^{b}	9.28	2.89
SEM	2.98	0.19	0.19	0.13	0.20	0.22	0.32	0.09	0.05	0.03	0.23	0.08
	P-value											
Sources of variation												
Strain	0.0232	NS	NS	NS	0.0021	0.0234	NS	NS	NS	NS	NS	<0.0001
Diet	0.0121	0.0444	0.0419	NS	NS	0.0411	NS	NS	NS	NS	0.0361	NS
Interaction	0.0097	NS	NS	NS	0.0113	0.0125	NS	NS	NS	0.0222	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] Digital image analysis – using the software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[4] Whole breast measurements: area = muscle surface area; length from right side = length from the top of the anatomical left shoulder diagonally to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[5] Slice A measurements: 1-cm wide cross-section of P. major taken from the left side of the muscle beginning at the top of the anatomical left shoulder and continuing diagonally towards the posterior end of the breast where the P. major was attached to the sternum. Length = length of Slice A; widest = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thinnest = thickness near the bottom of the breast.

[6] Slice B measurements: 1-cm wide cross-section of the P. major taken from the anatomical right side of the muscle from where the P. major was attached to the sternum and continuing outward to the edge of the P. major. Length = length of Slice B; widest = innermost thickness of muscle, closest to where the P. major was attached to the sternum.

Table 2-8. Effect of diet (CON or HIGH)[1] and strain (FF or SF)[2] on breast muscle conformation as determined by digital image analysis[3] in turkeys at 84 d of age

	Whole breast[4]					Slice A[5]				Slice B[6]	
	Area (cm2)	Length from right side (cm)	Length from left side (cm)	Keel (cm)	Middle (cm)	Widest (cm)	Length (cm)	Widest (cm)	Middle (cm)	Thinnest (cm)	Length (cm)	Widest (cm)
Strain												
FF	350.56	21.84	22.06	14.80	23.93	24.36	26.85	4.79^{b}	1.95^{b}	0.73	15.50^{b}	3.82^{b}
SF	354.84	21.67	21.77	14.98	24.19	24.52	27.18	5.09^{a}	2.19^{a}	0.76	16.31^{a}	4.22^{a}
SEM	4.15	0.15	0.16	0.15	0.21	0.21	0.25	0.10	0.06	0.02	0.19	0.12
Diet												
CON	332.08^{b}	21.25^{b}	21.40^{b}	14.56^{b}	23.19^{b}	23.69^{b}	26.31^{b}	4.71^{b}	1.92^{b}	0.74	15.47^{b}	3.83^{b}
HIGH	373.32^{a}	22.26^{a}	22.43^{a}	15.22^{a}	24.92^{a}	25.19^{a}	27.71^{a}	5.18^{a}	2.22^{a}	0.76	16.34^{a}	4.22^{a}
SEM	4.19	0.15	0.16	0.15	0.22	0.21	0.25	0.10	0.07	0.02	0.20	0.12
Strain X diet												
FF X CON	324.96	21.18	21.36	14.23^{b}	22.97	23.51	25.85	4.56	1.79	0.73	14.93	3.56
FF X HIGH	376.17	22.50	22.76	15.38^{a}	24.89	25.21	27.85	5.03	2.11	0.74	16.07	4.09
SF X CON	339.21	21.31	21.44	14.90^{ab}	23.42	23.87	26.77	4.86	2.04	0.75	16.02	4.11
SF X HIGH	370.47	22.02	22.09	15.06^{a}	24.95	25.17	27.58	5.33	2.34	0.78	16.61	4.34
SEM	5.99	0.21	0.24	0.21	0.31	0.31	0.36	0.14	0.09	0.03	0.28	0.17
	P-value											
Sources of variation												
Strain	NS	NS	NS	NS	NS	NS	NS	0.0352	0.0118	NS	0.0039	0.0205
Diet	<0.0001	<0.0001	<0.0001	0.0021	<0.0001	<0.0001	0.0001	0.0011	0.0013	NS	0.0022	0.0263
Interaction	NS	NS	NS	0.019	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8% more crude protein including essential amino acids, and at least 6% more energy than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] Digital image analysis – using the software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[4] Whole breast measurements: area = surface area of muscle; length from right side = length from the top of the anatomical left shoulder diagonally to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[5] Slice A measurements: 1-cm wide cross-section of P. major taken from the left side of the muscle beginning at the top of the anatomical left shoulder and continuing diagonally towards the posterior end of the breast where the P. major was attached to the sternum. Length = length of Slice A; widest = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thinnest = thickness near the bottom of the breast.

[6] Slice B measurements: 1-cm wide cross-section of the P. major taken from the anatomical right side of the muscle from where the P. major was attached to the sternum and continuing outward to the edge of the P. major. Length = length of Slice B; widest = innermost thickness of muscle, closest to where the P. major was attached to the sternum.

3.0 EFFECTS OF NUTRIENT DENSITY ON CARCASS TRAITS AND REPRODUCTIVE EFFICIENCY IN FAST- AND SLOW-FEATHERING TURKEY HENS

3.1 INTRODUCTION

Feather sexing based on wing feather development at hatch is commonly used in chicken production because it is faster, cheaper and less stressful for chicks than vent-sexing (Harris et al., 1984). The gene used for feather sexing chickens based on wing feather development (designated as K^+) is genetically dominant and sex-linked (Serebrovsky, 1922; Warren, 1925). Male broiler chickens with this gene have reduced primary and secondary feather development when compared to females and are therefore easily distinguishable at hatching. The implications of degree of feather cover with regard to metabolic requirements and growth during rearing were discussed in the previous chapter.

Egg production in SF birds compared to FF birds varies (Chambers et al., 1993). Decreased egg production has been reported in SF stocks, including layers (Harris et al., 1984; Saleh et al., 1987), broiler breeders (O'Sullivan et al., 1991) and turkeys (Zakrzewska, 1995) compared to FF birds. In White Leghorn dam lines, this may be partially attributed to higher infection and shedding rates for leukosis viruses (ALV) in SF than in FF birds. In egg-type and broiler breeder hens, decreased production has been connected to the expression of the 'ev21' viral gene, which is closely associated with the K^+ allele and encodes for infectious lymphoid leukosis virus (Harris et al., 1984; O'Sullivan et al. 1991). However, Dunnington and Siegel (1986) and Katanbaf et al. (1989) concluded that reproductive factors were minimally affected by sex-linked feathering alleles in broiler breeder stock. Inconsistent results with regard to the SF

phenotype in various stocks may be due to differences in research techniques related to diet and environment, as well as changes in the genetic background in domestic poultry over time. It also suggests intereraction of the K gene with other genes present in the genome. (Chambers et al., 1993).

The pre-lay period 4 to 6 wk before onset of lay is associated with increased nutrient and energy requirements (Cave, 1984; Brake et al., 1985). The pre-lay period corresponds to the time of development of the liver and reproductive organs. When preparing for follicle development, the liver uses protein to produce components of eggs, such as yolk proteins (Schjeide et al. 1963). Yu and Marquardt (1974) showed that oviduct dry mass per cell increases in preparation for egg production, establishing hormone receptors and subsequent tissue responsiveness to hormones. Sexual maturity can be attained only after certain thresholds have been met, including age, BW and body composition (Soller et al., 1984). Therefore, adequate nutrient reserves are important for reproduction to occur. Reproduction can be delayed, decreased or halted when there is not enough energy available for processes beyond body maintenance.

Adequate body composition threshold levels for reproduction in poultry can be achieved by increasing the level of dietary protein. Increased dietary protein during the pre-lay period (Cave 1984; Brake et. al. 1985) and during production (Bowmaker and Gous, 1989) has been shown to increase egg production in broiler breeders. Turkeys fed ad libitum had more yellow follicles due to increased follicular recruitment than feed-restricted turkeys (Hocking, 1992). Ad libitum feeding resulted in increased percent carcass fat, partially due to more ovarian follicles producing more estrogen. Increased dietary protein during production allows for adequate protein for processes related to egg formation (i.e., shell formation and albumen production).

Delaying photostimulation for a short time can improve egg production. With feed-restricted broiler breeders, this allows smaller birds to increase in frame size, muscle mass and organ development prior to onset of lay with no detrimental effect to production (Yuan et al., 1994; Robinson et al., 1996). Woodard et al. (1974) found that delayed photostimulation increased egg production by decreasing the number of multiple ovulations in turkeys. Size of early eggs from delay-photostimulated broiler breeders is larger compared to birds photostimulated earlier (Joseph, 2000; Joseph et al., 2002). Hocking (1992) reported increased egg production in delay-photostimulated turkeys because of decreased incidence of multiple hierarchies on the ovary and a subsequent decrease in non-settable eggs. Delaying photostimulation allows feed-restricted breeder hens to respond to light stimulation in a more uniform manner, which may increase BW uniformity and egg production by increasing early egg size, settable egg production and persistency of lay. Economic benefits achieved by this approach include decreased electricity and feed costs (Siopes, 1999).

A sex-linked gene for slow feathering was incorporated into a commercial line of Large White turkeys. Successful development of feather-sexable lines would benefit the turkey industry by reducing sexing errors, poult stress and processing costs at the hatchery. The objective of the current research was to characterize the current genetic performance of SF birds as well as parameters of reproductive efficiency and carcass morphology during lay in FF and SF turkey hens in response to increased nutrient density and delayed photostimulation. It was expected from the results of previous work that increased nutrient density before the start of lay would positively affect egg production, as birds would have increased nutrient reserves in preparation for egg

formation. Similarily, it was expected that delaying photostimulation would also improve reproductive parameters in turkey hens.

3.2 MATERIALS AND METHODS

Stocks and management

A total of 226 SF and 226 FF hens remaining from the experiment described in Chapter 2 were randomly distributed to one of 32 floor pens per strain in a light-tight facility (n=~12 per pen). Each strain was fed either a control diet (CON), or a diet high in energy and protein (HIGH). The CON diet was formulated as a standard commercial hen diet to meet breeder-recommended nutrient levels[4]. The HIGH diet contained at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet. The diets were fed as a breeder (1) from photostimulation to 38 or 40 wk, a breeder (2) from 38 or 40 wk to 46 or 48 wk, and a breeder (3) from 46 or 48 wk to 56 wk (Table 3-1). Birds were photostimulated at either 29 wk or 31 wk. The lighting program during rearing was as follows: Day 1, 24L:0D; Day 2 to 16 wk, 12L:12D; and 16 wk to photostimulation (29 or 31 wk), 6L:18D. The lighting program after photostimulation was 14L:10D. Feed and water were provided ad libitum. The temperature was maintained at approximately 15 to 17°C. BW and feed consumption were recorded biweekly until 56 wk of age.

Carcass parameters

At both photostimulation and at sexual maturity, 96 pre-assigned birds were processed. Sexual maturity was defined by the age at first egg. The remaining 260 birds were processed at the end of lay (56 wk). At processing, birds were killed by cervical dislocation and individually weighed. External measurements (shank and keel lengths,

[4] Hybrid Grade Maker Breeder Management Guide, Hybrid Turkeys, Kitchener, ON

thoracic circumference and width) were obtained to assess frame size. Using a vernier caliper, shank length was determined by measuring the length of the tibiotarsus (from the top of the hock joint to the bottom of the footpad), and keel length was determined by measuring the distance from the hypocleido-clavical joint to the caudal end of the sternum. Thoracic width was determined by using vernier calipers placed under the wings, just below the clavicle bones at approximately the widest point on the chest. Thoracic circumference was measured by wrapping a flexible measuring tape snugly under the birds' wings around the approximate widest point of the chest cavity, joining up at the hypocleido-clavical joint. Internal measurements included weights of P. major, P. minor, liver, fatpad, stroma, ovary and oviduct. Total breast weight was calculated by the sum of the pectoralis major and pectoralis minor. Ovaries were weighed and dissected to determine the number and the weight of the large yellow follicles (LYF), small yellow follicles (SYF) and atretic follicles. The stroma weight was measured by weighing the ovary after the LYF and atretic LYF were removed. Follicles were categorized as follows: LYF: a follicle that was greater than 10 mm in diameter, SYF: a follicle that was 5 to 10 mm in diameter. Atretic follicles were recognized by their shrunken and discolored appearance, and their incidence recorded, as described in Gilbert et al. (1983). Oviduct contents were removed before weighing the oviduct.

The area and thickness of the P. major were measured using the Northern Exposure® digital image analysis system[5]. These data were collected at photostimulation, sexual maturity and end of lay to objectively characterize breast muscle morphology and uniformity. The P. major was placed on a clean, white surface and peripheral fat and tissue was removed. A digital image was then taken and measured

[5] Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

using the image analysis software. First, the area was determined (Figure 3-1). Subsequently, measurements were taken to compare the conformation as well as the uniformity of the P. major. These included length (lines 1 and 2), center length (line 3), horizontal length at the widest point (line 4) and horizontal length at the middle (line 5; Figure 3-1). Cross-sections of the P. major were not taken with double-bladed scalpels as described in Chapter 3 due to the thickness of the P. major of adult birds compared to that of juvenile birds. Instead, the internal thickness of the breast was measured by piercing wooden skewers into the P. major at three consistent points (points 6, approximate thickest point; 7, approximate midpoint; and 8, approximate thinnest point; Figure 3-1) and marking the thickness of the P. major with a permanent marker on the skewer while it remained in the breast. The skewer was then removed from the P. major, and the marks on the skewers were measured by the same individual using plastic calipers and recorded. This was used to describe the muscle distribution of the P. major from the top of the breast, through the widest part across the breast, down to the posterior end of the P. major to the thinnest part of the breast.

Egg production

Hens were trap-nested to record egg production data from individual birds. This process is explained in detail in Appendix A. Daily individual records of egg production, egg weight, and egg quality were collected. These data were used to calculate total egg production, average sequence lengths, pause lengths, number of ovulations and to determine end of lay. No management techniques were used to control the incidence of incubation behaviour, characterized by cessation of egg production, and aggression in some birds.

Statistical analysis

Egg production records were analyzed for differences in total egg production, average sequence length and prime sequence length using the Egg Production and Sequence Analyzer.[6] The effects of age at photostimulation, strain, diet and their interactions on the parameters measured were assessed by two-way analysis of variance using the General Linear Model (GLM) procedure of SAS® (SAS Institute, Inc. 1996). Following a significant F-test ($P < 0.05$), means were separated using the t-test procedure of SAS® (SAS Institute, Inc. 1996). Unless otherwise stated, significance was assessed at the $P < 0.05$ level. The experimental protocol followed the *Guide to the Care and Use of Experimental Animals* (Canadian Council on Animal Care, 1984) and was approved by the Animal Policy and Welfare Committee of the Faculty of Agriculture, Forestry and Home Economics of the University of Alberta.

3.3 RESULTS AND DISCUSSION

Body weight

Hens photostimulated at 31 wk were 5.5 % or 0.5 kg heavier than birds photostimulated at 29 wk from 34 to 38 wk (Table 3-2). This indicates that delaying photostimulation had a positive effect on BW before photostimulation in this trial, allowing birds to gain weight. This effect extends to the period early in lay when nutrient demands are increased during peak egg production. This corresponds to the approximate period of peak egg production. Similar results were reported in broiler breeders (Joseph et al., 2002) and turkey breeder hens (Siopes, 1999) that had been delay-photostimulated. No difference in BW was observed in broiler breeders

[6] Version 3.00 © 1999. Alberta Agriculture, Food and Rural Development, Edmonton, AB, Canada, T6H 5T6

photostimulated later compared to those photostimulated at a breeder-recommended age (Nøddegaard et al., 2000).

From 28 wk to 56 wk, FF hens were on average 8.0% or 0.8 kg heavier than SF hens. Katanbaf et al. (1989) observed no difference in BW of SF and FF broiler breeders. O'Sullivan et al. (1991) found that SF broiler breeders were heavier than FF birds at the onset of egg production. An interaction of delaying photostimulation and genotype significantly increased BW of FF birds only at 34 wk, but not BW of SF hens (Table 3-3).

Nutrient density had no effect on BW during lay, as also shown by Cave (1984), Lilburn and Myers-Miller (1990) and Joseph (2000). Nutrient density had minimal effect and this implies that BW during lay is affected largely by strain. Breeders have already achieved their target growth potential by this time.

Carcass morphology

Effect of age at photostimulation

Photostimulating hens at 31 wk compared to 29 wk had no effect on carcass parameters at photostimulation or at sexual maturity (Tables 3-4; 3-5; 3-6; 3-7; 3-8; 3-9). At end of lay, early photostimulation resulted in increased shank length by 2.3% and absolute fatpad weight by 10.5% (Table 3-10). Keel length, and absolute ovary and oviduct weights were increased by 2.5%, 20.7% and 17.3%, respectively in birds photostimulated at 31 wk compared to 29 wk. This agrees with Robinson et al. (1996) and Renema et al. (2001a; 2001b), who reported proportionately increased organ growth and frame size in broiler breeders photostimulated at a later age. The current findings are in contrast to broiler breeders that were photostimulated later and showed an increase in frame size estimates at sexual maturity and a decrease in frame size estimates at end of

lay (Joseph et al., 2002). Turkey breeders have not been as heavily selected for growth compared to broiler breeders, so the broiler breeders may not have been able to maintain both body size and egg production throughout lay. The increase in keel length may have been a result of nutrient partitioning away from shank bone growth. Carcass fat may have been used to maintain laying condition until the end of lay.

Effect of strain

At photostimulation, FF birds had increased processing BW by 10.0%, breast width by 5.6%, absolute fatpad weight by 15.1%, and liver weight relative to BW by 0.06% when compared to SF birds (Table 3-4). No strain differences were noted in carcass morphology at sexual maturity (Table 3-6). At end of lay, FF hens had greater shank length by 2.1%, absolute liver weight by 15.4% and lower absolute fatpad weight by 9.3% compared to SF hens (Table 3-10). Absolute ovary weight (49%), absolute and % oviduct weight (52% and 0.57%, respectively), stroma weight (25%) and number of LYF (1.7 follicles) was increased in FF hens compared to SF hens at end of lay (Table 3-12). Previous work in SF stocks has focused on egg production, and not on carcass morphology. It can be concluded that FF hens were in better condition for lay compared to SF hens. Although the strains were equal in terms of BW and frame size at sexual maturity, the FF hens retained more protein reserves than SF birds, as indicated by increased skeletal and reproductive organ growth, and decreased carcass fat.

Effect of nutrient density

Increased nutrient density had no effect on carcass morphology at photostimulation or at sexual maturity (Tables 3-4, 3-6). Feeding the HIGH diet decreased shank length (1.8%) and absolute fatpad weight (13.1%) compared to feeding the CON diet at end of lay (Table 3-10). Keel length was increased only in FF hens fed

the HIGH diet. Absolute fatpad weight was increased in SF birds photostimulated at 29 wk compared to FF birds at the end of lay. This is supported by Renema et al. (1995; 2001a; 2001b). These results indicate that additional nutrients were allocated toward body protein and egg production instead of carcass fat at the end of lay. The SF hens did not respond to increased nutrient density with respect to changes in carcass morphology, however, SF birds that were photostimulated later used nutrients and energy for body protein and organ development.

Breast morphology

No differences in breast muscle morphology were observed in hens at photostimulation or at sexual maturity in response to delayed age at photostimulation, strain or diet (Tables 3-14; 3-15; 3-16; 3-17). End-of-lay hens photostimulated at 31 wk had increased breast thickness at point 6, at the caudal end of the P. major (Figure 3-1) compared to hens photostimulated at 29 wk. Although effects of delayed photostimulation on P. major development were minimal, 31 wk birds were able to maintain muscle protein in the caudal portion of the muscle where it is usually the thinnest. Breast thickness was increased at point 6 (Figure 3-1) in SF hens compared to FF hens at 56 wk. Thus, the SF hens showed a preferential partitioning of nutrients and energy into areas other than carcass fat and reproductive organ maintenance compared to FF hens at 56 wk.

Reproductive parameters

Attainment of sexual maturity

There was no difference in the mean number of days to first egg with regard to age at photostimulation, strain or diet treatments, as birds attained sexual maturity at 21.0 d after photostimulation on average in all cases (data not shown). The hens

photostimulated 2 wk later reached sexual maturity 2 wk later (34 wk) compared to the birds photostimulated earlier (32 wk). Siopes (1992, 1999) observed a slight acceleration in onset of lay of turkey breeder hens photostimulated later. Katanbaf et al. (1989) reported no difference in onset of lay in SF and FF broiler breeders.

Age at photostimulation and sequence data

Hens that were photostimulated at 31 wk showed peak production 3 wk later than 29 wk birds (Figure 3-2). However, there were no differences in total and settable egg production, number of pauses and sequences, average lengths of sequences and pauses, age at last egg laid, and number of ovulations between birds photostimulated at 29 and 31 wk (Table 3-20). Birds photostimulated later produced fewer double-yolked eggs (0.09 vs. 0.24). Hens photostimulated at 31 wk also showed an increase in egg production of 8.1% near the end of lay compared to 29 wk hens (Figure 3-2). This is supported by longer sequence lengths in 31 wk birds from 35 to 38 wk (approximately 0.5 d difference), from 44 to 49 wk (approximately 0.4 d difference, except at 47 wk), and at 53 wk (approximately 0.5 d) compared to 29 wk birds (Figure 3-5).

Age at photostimulation and percent egg production

Delaying photostimulation showed a positive effect on total egg production as these birds were able to produce the same number of eggs on average over a shorter period of time (Table 3-20). The absolute ovary and oviduct weights were increased in these birds at end of lay, but reproductive organ weight relative to BW and number of LYF were similar to that in hens photostimulated earlier at this time (Table 3-12). This indicates that the 31 wk birds may have been better prepared in terms of reproductive organ development at photostimulation, and this carried positive effects on egg production to the end of lay. The 31 wk birds may have had a more appropriate number

of LYF and ovary size relative to oviduct size and were able to produce the same number of eggs in a shorter lay cycle. Delaying photostimulation had no detrimental effect on production in broiler breeders (Yuan et al., 1994; Robinson et al., 1996; Noddegaard et al., 2000) and increased frame size, muscle growth and organ development (Yuan et al., 1994; Robinson et al., 1996). Early egg size was increased in broiler breeders (Joseph, 2000; Joseph et al., 2002), and multiple ovulations were reduced in turkeys (Woodard et al., 1974) that were photostimuated later. This decrease in non-settable eggs in the turkey was attributed to a decreased multiple hierarchies on the ovary (Hocking, 1992). Siopes (1999) observed a decrease in mean hen-day egg production between hens photostimulated at different times to 54 wk, and this was attributed to later-photostimulated birds being in production for a shorter time than birds photostimulated earlier, although egg weight was reduced in the latter to 16 wk of photostimulation. Early photostimulation is associated with small early egg size in turkeys (Hocking, 1992; Siopes, 1992).

Strain and sequence data

Sequence length was longer in FF hens than in SF hens throughout lay, the maximum difference of 4.5 d occurring at 35 wk (Figure 3-6). Prime sequence length (11.9 d vs 8.0 d), total egg production (98.9 vs. 58.2), number of settable eggs (97.2 vs. 57.9), average sequence length (3.8 vs. 2.7 d), age at last egg laid (49.9 d vs. 45.2 d) and number of ovulations (99.2 vs. 58.3) was increased in FF hens compared to SF hens (Table 3-20). The number of eggs laid without shells were 0.13 and 0.66 in SF and FF birds respectively. The number of double-yolked eggs was 0.02 in SF hens compared to 0.30 in FF hens. The SF hens laid fewer total defective eggs, but also had significantly decreased overall egg production compared to FF birds.

Strain and percent egg production

The FF hens had significantly higher average % egg production (55.1 vs. 33.2%) and peak production (76.3 vs. 68.4%) compared to SF hens (Figure 3-3). There was a high occurrence of broodiness observed in SF hens, as hens stopped laying, decreased in BW likely due to decreased feed intake, developed pale and dry vents, and in some cases, became aggressive. Some of the birds that went out of production resumed laying before the end of the trial, but overall, egg production was greatly reduced in SF hens. Zakrzewska (1995) reported decreased egg production and high incidence of broodiness in SF turkey hens compared to FF hens. The FF hens were better able to divert nutrients and energy to egg production compared to SF hens as a result of selection for production traits. As well, interaction of the SF phenotype with the rest of the genome, and pleiotropic effects related to nutrition and the environment were evident from the egg production data. It has been established that as the reproductive cycle progresses, egg production normally declines. This is not necessarily associated with hen age, as egg production and LH surge intervals were not affected in turkey hens that were selected for increased egg production and held under short-day (6L:18D) lighting, then photostimulated at either 30 wk or 70 wk (Liu et al., 2001). Factors associated with poorer egg production over the duration of include increased intervals between intrasequence LH surges in chickens (Lillpers and Wilhelmson, 1993, Liu et al., 2002), increased occurrence of pauses longer than 33 h between sequences in chickens (Robinson et al., 1990), an increased incidence of follicular atresia in chickens (Zakaria et al., 1983), loss of synchronization of ovulation and oviposition in chickens (Joyner et al., 1987; Applegate and Lilburn, 1996) and modified secretion of progesterone in turkeys (Liu et al., 2001). There was no evidence of increased atresia, defective egg

production or internal ovulation in SF hens to account for the observed decreased in egg production. Levels of gonadotropic hormones were not measured, but carcass data indicated that FF hens were in better condition to support reproduction. This is significant because it may indicate interactions of the SF phenotype with reproductive potential, such as small follicle development, which is associated with androgen and estrogen production (Robinson and Etches, 1986), or LYF development, which is associated mainly with progesterone production (Etches and Duke, 1984). Further gonadotropic research in SF hens could determine if differences in factors such as estrogen levels, LH baseline levels or surge amplitude (associated with effects on egg production), prolactin or thyroxine (associated with incubation behavior and cessation of lay) exist.

Nutrient density and sequence length

Nutrient density had minimal effect on egg production, the only difference occurring with regard to sequence length early in lay. Hens fed the CON diet had a longer sequence length (7.5 d vs. 7.0 d) at 35 wk compared to hens fed the HIGH diet (Figure 3-5). From 37 wk to 39 wk, hens fed the HIGH diet had approximately 0.5 d longer sequence lengths than hens fed the CON diet.

Overall, SF hens expressed different BW, carcass morphology and reproductive efficiency compared to FF hens. The SF hens had reduced BW and egg production compared to commercial birds during lay. Delaying photostimulation resulted in positive effects on BW, carcass morphology and egg production. Nutrient density had minimal effects on production in this trial. With continued genetic research regarding the effects of the SF gene in turkeys on reproductive efficiency, commercially viable, feather-sexable turkeys are a possibility.

3.4 REFERENCES

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Table 3 - 1. Ingredient and calculated nutrient composition of turkey rations fed from 29 wk to 56 wk of age

	Breeder 1 (29 wk to 36 wk)		Breeder 2 (36 wk to 46 wk)		Breeder 3 (46 wk to 56 wk)	
	Control	High	Control	High	Control	High
	g/1000 g					
Ingredients						
Ground corn	172.7	125.5	342.4	349.3	508.3	534.6
Wheat, HRS, ground	502.7	500.0	250.0	303.2	100.0	143.6
Ground oats	...	...	97.0	...	107.4	...
48% soybean meal	191.9	231.8	171.2	217.9	144.5	193.1
Ground limestone	61.2	61.1	62.0	61.8	68.3	68.1
Biofos	22.9	22.7	23.9	21.6	22.4	20.1
Canola oil	31.4	41.3	35.4	28.8	31.0	22.9
Choline chloride premix[1]	5.0	5.0	5.0	5.0	5.0	5.0
Hybrid vitamin premix[2]	2.2	2.2	2.2	2.2	2.2	2.2
Hybrid mineral premix[3]	1.1	1.1	1.1	1.1	1.1	1.1
NaCl	4.1	4.1	5.0	4.1	5.0	4.1
D,L -methionine	1.7	2.1	1.6	1.9	1.8	2.2
L-lysine HCl	2.1	2.1	2.2	2.2	1.9	1.9
Avizyme 1302[4]	0.5	0.5	0.5	0.5	0.5	0.5
Amprol	0.5	0.5	0.5	0.5	0.5	0.5
Total	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
Nutrient composition						
CP (%)[5]	18.5	20.0	16.3	18.3	14.3	16.3
CP (%)[6]	21.6	23.5	16.6	19.6	14.9	16.5
ME (Kcal/kg)[5]	2950	2975	2950	2950	2950	2950
Linoleic acid (%)[5]	1.5	1.6	1.9	1.7	2.1	1.9
Fat (%)[5]	4.9	5.7	5.9	5.0	5.8	4.8
Fibre (%)[5]	2.4	2.4	3.1	2.4	3.1	2.3
Calcium (%)[6]	3.3	3.3	3.0	2.1	3.2	3.1
Available P (%)[5]	0.6	0.6	0.6	0.5	0.5	0.5
Total P (%)[6]	0.9	0.9	0.8	0.9	0.7	0.7
Potassium (%)[5]	0.6	0.7	0.6	0.7	0.5	0.6
Chloride (%)[5]	0.3	0.3	0.4	0.3	0.4	0.3
Sodium (%)[5]	0.2	0.2	0.2	0.2	0.2	0.2
Choline (mg/kg)[5]	1259	1336	1134	1230	1016	1109
Methionine (%)[5]	0.43	0.52	0.41	0.51	0.44	0.52
Met + Cys (%)[5]	0.73	0.81	0.74	0.76	0.71	0.75
Lysine (%)[5]	1.03	1.12	0.91	1.09	0.87	0.92
Threonine (%)[5]	0.63	0.71	0.65	0.67	0.53	0.61
Arginine (%)[5]	1.01	1.23	1.07	1.10	0.83	1.01
Tryptophan (%)[5]	0.22	0.31	0.27	0.24	0.23	0.26

[1] Choline chloride premix provided choline at 100 mg per kilogram of diet

[2] Vitamin premix provided the following per kilogram of diet: vitamin A, 12,000 IU; vitamin D3, 3,000 IU; vitamin K, 2.0 mg; pantothenic acid, 20.0 mg; riboflavin 6.0 mg; folacin, 1.2 mg; niacin, 90.0 mg; thiamine, 3.0 mg; vitamin B12, 0.02 mg, biotin, 0.25 mg; vitamin E, 40 IU.

[3] Mineral premix provided the following in mg per kg of diet: I, 0.5; Mn, 75.0; Cu, 15.0; Zn, 80.0; Se, 0.1; Fe, 100.0.

[4] Danisco Animal Nutrition, Malboro, UK

[5] Calculated nutrient levels.

[6] Analyzed nutrient levels.

Table 3 - 2. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on BW in turkey hens from 28 wk to 56 wk of age

Age (wk)	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56
								kg							
PSTIM															
29 wk	9.6	9.7	9.8	9.6[b]	9.2[b]	9.1[b]	9.0	9.0	9.0	9.1	9.2	9.3	9.4	9.4	9.5
31 wk	9.8	9.8	9.9	10.0[a]	9.7[a]	9.3[a]	9.0	8.9	8.9	8.9	9.1	9.1	9.3	9.3	9.4
SEM	0.04	0.05	0.06	0.07	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.07	0.07	0.07	0.08
Strain															
FF	10.0[a]	10.2[a]	10.2[a]	10.1[a]	9.8[a]	9.5[a]	9.3[a]	9.3[a]	9.3[a]	9.4[a]	9.5[a]	9.6[a]	9.7[a]	9.7[a]	9.8[a]
SF	9.1[b]	9.4[b]	9.5[b]	9.4[b]	9.2[b]	8.9[b]	8.7[b]	8.6[b]	8.6[b]	8.7[b]	8.8[b]	8.9[b]	9.0[b]	9.0[b]	9.0[b]
SEM	0.06	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.07	0.08
Diet															
CON	9.5	9.7	9.8	9.7	9.4	9.2	9.0	8.9	9.0	9.0	9.2	9.3	9.4	9.4	9.5
HIGH	9.7	9.8	9.9	9.8	9.5	9.3	9.1	9.0	9.0	9.0	9.1	9.2	9.3	9.3	9.3
SEM	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08
Sources of variation															
PSTIM	NS	NS	NS	0.0002	0.0002	0.0143	NS	NS	NS	NS	NS	NS	NS	NS	NS
Strain	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

Table 3 - 3. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on BW in turkey hens from 28 wk to 56 wk of age

Age (wk)	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56
	kg														
Strain X diet															
FF X CON	9.9	10.1	10.2	10.1	9.7	9.4	9.2	9.2	9.2	9.3	9.4	9.5	9.7	9.7	9.8
FF X HIGH	10.0	10.3	10.3	10.2	9.9	9.7	9.4	9.3	9.4	9.4	9.6	9.6	9.7	9.7	9.7
SF X CON	9.1	9.3	9.5	9.4	9.2	8.9	8.7	8.7	8.7	8.7	8.9	9.0	9.2	9.1	9.1
SF X HIGH	9.3	9.4	9.5	9.5	9.1	8.9	8.7	8.6	8.5	8.6	8.7	8.7	8.8	8.9	8.9
SEM	0.05	0.07	0.09	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PSTIM X strain															
29 X FF	10.0	10.1	10.1	9.8[b]	9.5	9.3	9.2	9.2	9.2	9.4	9.4	9.6	9.6	9.7	9.7
29 X SF	9.2	9.4	9.6	9.3[c]	9.0	8.8	8.7	8.7	8.7	8.9	8.9	9.1	9.2	9.2	9.2
31 X FF	10.0	10.3	10.4	10.4[a]	10.1	9.7	9.4	9.3	9.4	9.4	9.5	9.6	9.7	9.8	9.8
31 X SF	9.3	9.4	9.5	9.5[bc]	9.3	9.0	8.6	8.6	8.5	8.5	8.6	8.7	8.9	8.8	8.9
SEM	0.05	0.07	0.09	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PSTIM X diet															
29 X CON	9.2	9.7	9.8	9.5	9.1	9.0	8.9	8.9	9.0	9.1	9.2	9.3	9.5	9.5	9.5
29 X HIGH	9.4	9.8	9.9	9.7	9.4	9.2	9.0	9.0	9.0	9.1	9.2	9.3	9.3	9.4	9.4
31 X CON	9.8	9.7	9.8	10.0	9.7	9.3	9.0	8.9	8.9	8.9	9.1	9.2	9.4	9.4	9.4
31 X HIGH	9.7	9.9	10.0	10.0	9.7	9.4	9.1	8.9	8.9	8.9	9.1	9.1	9.2	9.2	9.3
SEM	0.07	0.07	0.08	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sources of variation															
Strain X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	0.0333	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a-c] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

Table 3 - 4. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on carcass morphology in turkey hens at photostimulation (PSTIM)

						Breast muscle parameters										Reproductive parameters			
	BW	Shank length	Keel length	Thoracic circum.	Thoracic width	Breast wt.[4]		Pectoralis major wt.		Pectoralis minor wt.		Abdominal fatpad wt.		Liver wt.		Ovary wt.		Oviduct wt.	
	(kg)	(mm)	(mm)	(cm)	(cm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
PSTIM																			
29 wk	9.3	139.6	177.9	60.8	15.5	2,423.3	26.0	1,932.9	20.7	487.5	5.26	298.1	3.22	56.73	0.61	4.92	0.051	5.10	0.16
31 wk	9.7	140.3	181.1	61.5	15.8	2,480.8	25.7	1,974.6	20.4	506.2	5.25	282.4	2.91	57.89	0.59	3.23	0.033	2.91	0.14
SEM	0.1	0.9	1.1	0.4	0.1	54.0	0.6	54.2	0.5	5.6	0.056	13.6	0.12	1.82	0.017	1.42	0.013	1.92	0.022
Strain																			
FF	10.0[a]	142.0	179.9	62.1	16.1[a]	2,552.6	25.5	2,042.2	20.3	507.4	5.09	313.9[a]	3.15	57.88	0.57[b]	3.09	0.031	2.92	0.15
SF	9.0[b]	138.0	179.1	60.1	15.2[b]	2,351.5	26.2	1,865.3	20.8	486.3	5.42	266.6[b]	2.98	56.74	0.63[a]	5.06	0.053	5.09	0.15
SEM	0.1	0.9	1.1	0.4	0.1	54.0	0.6	54.2	0.5	5.6	0.056	13.6	0.12	1.82	0.017	1.42	0.013	1.88	0.022
Diet																			
CON	9.4	139.6	178.3	61.2	15.8	2,392.9	25.6	1,909.0	20.4	483.9	5.20	302.8	3.22	57.15	0.61	3.24	0.034	3.16	0.15
HIGH	9.6	140.3	180.7	61.1	15.5	2,511.2	26.1	1,998.5	20.7	509.8	5.31	277.8	2.90	57.47	0.59	4.92	0.050	4.84	0.15
SEM	0.1	0.9	1.1	0.4	0.1	54.0	0.6	54.2	0.5	5.6	0.056	13.6	0.12	1.82	0.017	1.42	0.013	1.90	0.022
	P-values																		
Sources of variation																			
PSTIM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Strain	0.0002	NS	NS	NS	0.0018	NS	NS	NS	NS	NS	NS	0.0358	NS	NS	0.0365	NS	NS	NS	NS
Diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 3 - 5. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on carcass morphology in turkey hens at photostimulation (PSTIM)

						Breast muscle parameters										Reproductive parameters			
	BW	Shank length	Keel length	Thoracic circumf.	Thoracic Width	Breast wt.[4]		Pectoralis major wt.		Pectoralis minor wt.		Abdominal fatpad wt.		Liver wt.		Ovary wt.		Oviduct wt.	
	(kg)	(mm)	(mm)	(cm)	(cm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
Strain X diet																			
FF X CON	9.7	141.5	178.2	61.4	16.1	2,435.1	25.1	1,950.4	20.1	484.7	5.00	335.8	3.46	56.85	0.58	3.27	0.033	3.42	0.16
FF X HIGH	10.3	142.4	181.5	62.9	16.1	2,670.1	26.0	2,134.1	20.6	530.1	5.18	292.1	2.84	58.90	0.56	2.92	0.029	2.41	0.14
SF X CON	9.0	137.8	178.4	60.9	15.5	2,350.8	26.2	1,867.7	20.8	483.1	5.39	269.8	2.99	57.44	0.63	3.20	0.035	2.90	0.14
SF X HIGH	8.9	138.3	179.9	59.3	15.0	2,352.3	26.1	1,862.8	20.7	489.5	5.44	263.5	2.97	56.03	0.63	6.92	0.070	7.28	0.17
SEM	0.2	1.3	1.6	0.6	0.2	77.3	0.9	76.6	0.8	8.0	0.080	19.2	0.16	2.57	0.024	2.00	0.019	2.88	0.034
PSTIM X strain																			
29 X FF	9.9	142.7	178.0	61.6	16.0	2,589.8	26.3	2,082.2	21.0	501.8	5.12	317.9	3.25	57.66	0.58	3.13	0.032	3.49	0.13
29 X SF	8.7	136.6	177.8	60.0	15.1	2,256.9	25.8	1,783.6	20.4	473.2	5.40	278.3	3.19	55.79	0.64	6.72	0.069	6.70	0.20
31 X FF	10.2	141.3	181.7	62.6	16.2	2,515.3	24.8	2,002.3	19.7	513.1	5.06	309.9	3.05	58.10	0.57	3.06	0.030	2.35	0.18
31 X SF	9.2	139.4	180.5	60.3	15.4	2,446.2	26.6	1,946.9	21.1	499.3	5.43	255.0	2.77	57.68	0.62	3.40	0.036	3.47	0.11
SEM	0.2	1.3	1.6	0.6	0.2	77.3	0.9	76.6	0.8	8.0	0.080	19.2	0.16	2.57	0.024	2.00	0.019	2.94	0.034
PSTIM X diet																			
29 X CON	9.2	139.0	176.5	60.8	15.8	2,345.2	25.7	1,871.1	20.5	474.1	5.20	309.6	3.38	56.60	0.62	2.99	0.032	3.15	0.14
29 X HIGH	9.5	140.3	179.3	60.8	15.3	2,501.5	26.4	1,994.7	20.9	500.9	5.33	286.6	3.06	56.85	0.59	6.85	0.069	7.04	0.18
31 X CON	9.6	140.3	180.1	61.6	15.8	2,440.6	25.6	1,946.9	20.4	493.7	5.20	296.0	3.07	57.70	0.60	3.48	0.036	3.17	0.16
31 X HIGH	9.8	140.4	182.1	61.4	15.8	2,520.9	25.7	2,002.2	20.4	518.7	5.29	268.9	2.75	58.08	0.59	2.99	0.030	2.65	0.13
SEM	0.2	1.3	1.6	0.6	0.2	77.3	0.9	76.6	0.8	8.0	0.080	19.2	0.16	2.57	0.024	2.00	0.019	2.94	0.034
	P-values																		
Sources of variation																			
Strain X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 3 - 6. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on carcass morphology in turkey hens at sexual maturity

						Breast muscle parameters									
	BW	Shank length	Keel length	Thoracic circumf.	Thoracic width	Breast wt.[4]		Pectoralis major wt.		Pectoralis minor wt.		Abdominal fatpad wt.		Liver wt.	
	(kg)	(mm)	(mm)	(cm)	(cm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
PSTIM															
29 wk	10.0	141.1	179.3	63.8	16.9	2,272.3	22.7	1,814.4	18.1	457.9	4.58	310.3	3.11	118.2	1.19
31 wk	10.2	139.4	182.7	64.7	17.2	2,346.1	22.9	1,878.2	18.4	466.1	4.58	308.4	3.04	118.4	1.17
SEM	0.2	0.9	1.6	0.6	0.2	56.7	0.3	48.6	0.5	8.7	0.95	12.3	0.12	2.8	0.026
Strain															
FF	10.3	141.7	181.5	64.7	17.3	2,362.7	22.9	1,892.9	18.4	467.9	4.55	309.7	3.01	121.1	1.18
SF	9.9	138.8	180.4	63.8	16.8	2,255.7	22.8	1,799.6	18.2	456.1	4.61	309.0	3.14	115.5	1.17
SEM	0.2	0.9	1.6	0.6	0.2	56.0	0.3	48.0	0.7	8.7	0.54	12.3	0.12	2.8	0.03
Diet															
CON	10.0	140.9	180.6	64.1	17.1	2,303.8	23.0	1,841.7	18.5	460.3	4.62	313.1	3.16	117.8	1.19
HIGH	10.2	139.6	181.3	64.4	17.0	2,314.6	22.6	1,850.9	18.1	463.7	4.53	305.7	2.99	118.8	1.17
SEM	0.2	1.0	1.7	0.6	0.2	55.3	0.3	47.4	0.4	8.8	0.67	12.5	0.12	2.9	0.026
P-values															
Sources of variation															
PSTIM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Strain	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 3 - 7. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on carcass morphology in turkey hens at sexual maturity

						Breast muscle parameters									
						Breast wt.[4]		Pectoralis major wt.		Pectoralis minor wt.		Abdominal fatpad wt.		Liver wt.	
	BW (kg)	Shank length (mm)	Keel, length (mm)	Thoracic circumf. (cm)	Thoracic width (cm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
Strain X diet															
FF X CON	10.1	142.0	180.5	64.3	17.3	2,346.6	23.1	1,882.5	18.7	460.5	4.57	317.7	3.15	122.2	1.22
FF X HIGH	10.5	141.4	182.5	65.2	17.3	2,378.8	22.7	1,903.4	18.1	475.4	4.53	301.8	2.87	120.0	1.15
SF X CON	9.8	139.7	180.7	64.0	17.0	2,261.0	23.0	1,801.0	18.3	460.1	4.68	308.4	3.16	113.4	1.16
SF X HIGH	10.0	137.9	180.1	63.6	16.7	2,250.4	22.6	1,798.3	18.0	452.0	4.53	309.6	3.12	117.7	1.19
SEM	0.2	1.4	2.4	0.8	0.3	81.2	0.4	69.6	0.9	12.9	0.50	18.3	0.18	4.2	0.039
PSTIM X strain															
29 X FF	10.3	142.4	180.0	64.5	17.2	2,347.6	22.8	1,879.1	18.2	468.5	4.55	304.4	2.95	117.7	1.15
29 X SF	9.7	139.9	178.5	63.2	16.6	2,197.0	22.6	1,749.7	18.0	447.3	4.60	316.3	3.27	118.7	1.23
31 X FF	10.3	141.0	183.0	64.9	17.4	2,377.8	23.0	1,906.8	18.5	467.3	4.55	315.1	3.07	124.5	1.22
31 X SF	10.1	137.7	182.4	64.4	17.0	2,314.4	22.9	1,849.6	18.3	464.8	4.61	301.7	3.01	112.3	1.12
SEM	0.2	1.4	2.4	0.8	0.3	79.2	0.4	67.9	0.6	12.6	0.75	17.9	0.18	4.1	0.038
PSTIM X diet															
29 X CON	10.1	142.4	180.7	64.3	17.3	2,296.1	22.7	1,835.2	18.2	460.8	4.57	325.6	3.22	119.8	1.19
29 X HIGH	9.9	139.9	177.9	63.4	16.5	2,248.6	22.7	1,793.6	18.1	455.0	4.58	295.1	2.99	116.6	1.18
31 X CON	9.8	139.4	180.6	64.0	16.9	2,311.6	23.3	1,848.2	18.8	459.7	4.68	300.5	3.09	115.7	1.18
31 X HIGH	10.5	139.3	184.8	65.4	17.5	2,380.6	22.5	1,908.2	18.1	472.4	4.48	316.3	3.00	121.0	1.15
SEM	0.2	1.4	2.4	0.8	0.3	75.2	0.4	67.9	0.5	12.6	0.080	17.9	0.18	4.1	0.038
	P-values														
Sources of variation															
Strain X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 3 - 8. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on reproductive parameters in turkey hens at sexual maturity

	Ovary wt.		Oviduct wt.		Stroma wt.	Number LYF[5]
	(g)	(%)[4]	(g)	(%)[4]	(g)	
PSTIM						
29 wk	143.3	1.43	80.8	0.81	12.4	12.5
31 wk	147.3	1.45	86.6	0.86	11.4	12.2
SEM	4.0	0.03	1.6	0.02	0.5	0.4
Strain						
FF	144.9	1.41	86.5	0.85	11.8	12.8
SF	145.7	1.46	80.9	0.82	12.0	12.0
SEM	4.0	0.03	1.6	0.02	0.5	0.4
Diet						
CON	142.9	1.43	82.9	0.84	11.5	12.4
HIGH	147.7	1.44	84.5	0.83	12.3	12.4
SEM	4.1	0.03	1.6	0.02	0.5	0.4
---------- *P -values* ----------						
Sources of variation						
PSTIM	NS	NS	NS	NS	NS	NS
Strain	NS	NS	NS	NS	NS	NS
Diet	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Indicates as a % of BW

[5] LYF = large yellow follicles on the ovary

Table 3 - 9. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on reproductive parameters in turkey hens at sexual maturity

	Ovary wt.		Oviduct wt.		Stroma wt.	Number LYF[5]
	(g)	(%)[4]	(g)	(%)[4]	(g)	
Strain X diet						
FF X CON	140.9	1.40	84.2	0.84	11.8	12.4
FF X HIGH	148.9	1.42	88.8	0.85	11.8	13.1
SF X CON	144.9	1.47	81.5	0.83	11.2	12.4
SF X HIGH	146.5	1.46	80.3	0.81	12.7	11.6
SEM	6.0	0.05	2.4	0.028	0.7	0.5
PSTIM X strain						
29 X FF	145.0	1.41	84.7	0.82	11.8	13.1
29 X SF	141.6	1.44	76.9	0.79	13.0	11.9
31 X FF	144.8	1.41	88.3	0.87	11.9	12.4
31 X SF	149.7	1.48	84.8	0.85	10.9	12.1
SEM	5.8	0.05	2.4	0.027	0.7	0.5
PSTIM X diet						
29 X CON	146.6	1.45	80.8	0.81	12.2	13.0
29 X HIGH	140.0	1.40	80.8	0.81	12.7	12.0
31 X CON	139.2	1.42	84.9	0.87	10.9	11.7
31 X HIGH	155.4	1.48	88.2	0.84	11.9	12.8
SEM	5.8	0.05	2.4	0.027	0.7	0.6
	----------		*P -values*			----------
Sources of variation						
Strain X diet	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Indicates as a % of BW

[5] LYF = large yellow follicles on the ovary

Table 3 - 10. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on carcass morphology in turkey hens at end of lay

						Breast muscle parameters									
	BW	Shank length	Keel length	Thoracic circumf.	Thoracic width	Breast wt.[4]		Pectoralis major wt.		Pectoralis minor wt.		Abdominal fatpad wt.		Liver wt.	
	(kg)	(mm)	(mm)	(cm)	(cm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
PSTIM															
29 wk	9.3	141.3[a]	173.1[b]	59.2	16.0	2,219.0	23.8	1,731.6	18.6	487.4	5.22	258.5[a]	2.76	110.7	1.20
31 wk	9.2	138.1[b]	177.5[a]	59.3	16.3	2,228.8	26.0	1,751.7	19.0	477.1	5.18	231.3[b]	2.71	118.4	1.44
SEM	0.1	0.6	1.1	0.2	0.1	25.8	1.5	21.6	1.6	5.9	0.67	7.6	0.19	3.4	0.13
Strain															
FF	9.6	141.1[a]	173.8	59.2	16.0	2,231.1	25.1	1,743.8	18.2	487.3	5.08	232.9[b]	2.62	124.1[a]	1.45
SF	9.0	138.2[b]	176.8	59.3	16.3	2,216.7	24.7	1,739.5	19.4	477.2	5.32	256.9[a]	2.85	105.0[b]	1.18
SEM	0.1	0.6	1.1	0.2	0.1	26.1	1.6	21.8	0.9	6.0	0.40	7.5	0.20	3.4	0.13
Diet															
CON	9.4	141.0[a]	174.4	59.2	16.1	2,230.9	23.8	1,747.7	18.6	483.2	5.15	262.1[a]	2.78	111.7	1.20
HIGH	9.2	138.4[b]	176.3	59.3	16.3	2,216.9	26.0	1,735.6	18.9	481.3	5.25	227.7[b]	2.69	117.5	1.44
SEM	0.1	0.6	1.1	0.2	0.1	26.2	1.6	21.4	1.8	5.8	0.58	7.7	0.19	3.3	0.13
	P-values														
Sources of variation															
PSTIM	NS	0.0005	0.0102	NS	NS	NS	NS	NS	NS	NS	NS	0.0182	NS	NS	NS
Strain	NS	0.0015	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0349	NS	0.0005	NS
Diet	NS	0.0036	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0037	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 3 - 11. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on carcass morphology in turkey hens at end of lay

						Breast muscle parameters									
	BW	Shank length	Keel length	Thoracic circumf.	Thoracic width	Breast wt.[4]		Pectoralis major wt.		Pectoralis minor wt.		Abdominal fatpad wt.		Liver wt.	
	(kg)	(mm)	(mm)	(cm)	(cm)	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]	(g)	(%)[5]
Strain X diet															
FF X CON	9.7	143.2	170.9[b]	59.0	15.8	2,211.5	22.9	1,724.6	17.9	486.9	5.04	256.8	2.63	120.8	1.26
FF X HIGH	9.5	139.0	176.6[ab]	59.5	16.2	2,250.7	27.3	1,763.1	18.5	487.6	5.12	209.0	2.62	127.5	1.65
SF X CON	9.1	138.7	177.8[a]	59.4	16.4	2,250.2	24.7	1,770.7	19.5	479.5	5.27	267.5	2.94	102.6	1.14
SF X HIGH	8.8	137.7	175.9[ab]	59.2	16.3	2,183.2	24.7	1,708.2	19.3	475.0	5.38	246.3	2.75	107.5	1.22
SEM	0.1	0.8	1.6	0.3	0.1	36.6	2.2	31.3	1.5	8.5	0.40	11.0	0.27	4.7	0.18
PSTIM X strain															
29 X FF	9.5	143.0	170.2	58.5	15.5	2,177.1	22.8	1,695.2	17.8	481.9	5.05	233.6[b]	2.43	122.0	1.29
29 X SF	9.1	139.6	176.0	59.8	16.5	2,260.9	24.7	1,768.1	19.4	492.8	5.40	283.4[a]	3.09	99.5	1.10
31 X FF	9.6	139.2	177.4	60.0	16.5	2,285.1	27.4	1,792.5	18.6	492.6	5.12	232.2[b]	2.82	126.2	1.62
31 X SF	8.8	136.9	177.7	58.7	16.2	2,172.6	24.6	1,710.9	19.4	461.7	5.24	230.4[b]	2.60	110.6	1.26
SEM	0.1	0.8	1.6	0.3	0.1	35.3	2.1	31.5	1.8	8.1	0.50	10.4	0.28	4.7	0.18
PSTIM X diet															
29 X CON	9.4	142.0	172.2	59.2	16.0	2,225.9	23.7	1,734.5	18.5	491.4	5.23	271.4	2.87	106.7	1.15
29 X HIGH	9.3	140.6	173.9	59.1	16.0	2,212.1	23.8	1,728.7	18.6	483.4	5.21	245.6	2.65	114.7	1.24
31 X CON	9.4	140.0	176.5	59.1	16.2	2,235.8	23.9	1,760.9	18.8	475.0	5.08	252.8	2.70	116.6	1.26
31 X HIGH	9.1	136.1	178.6	59.6	16.5	2,221.8	28.1	1,742.5	19.2	479.3	5.28	209.8	2.72	120.2	1.63
SEM	0.1	0.8	1.5	0.3	0.1	37.5	2.1	29.6	2.0	8.6	0.85	11.0	0.27	4.8	0.17
	P-values														
Sources of variation															
Strain X diet	NS	NS	0.0250	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0247	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Breast weight includes both P. major and P. minor

[5] Indicates as a % of BW

Table 3 - 12. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on reproductive parameters in turkey hens at end of lay

	Ovary wt.		Oviduct wt.		Stroma wt.	Number LYF[5]
	(g)	(%)[4]	(g)	(%)[4]	(g)	
PSTIM						
29 wk	73.2[b]	0.79	65.2[b]	0.71	13.0	7.7
31 wk	92.3[a]	1.13	78.8[a]	0.96	12.0	8.3
SEM	5.0	0.13	3.7	0.10	0.5	0.2
Strain						
FF	109.5[a]	1.28	97.2[a]	1.12[a]	14.5[a]	8.8[a]
SF	56.1[b]	0.64	46.7[b]	0.54[b]	10.6[b]	7.1[b]
SEM	5.0	0.13	3.7	0.10	0.6	0.3
Diet						
CON	81.6	0.87	69.9	0.75	12.1	8.1
HIGH	84.0	1.05	74.0	0.91	13.0	7.8
SEM	5.0	0.13	3.6	0.10	0.6	0.2
---------- *P-values* ----------						
Sources of variation						
PSTIM	0.0116	NS	0.0152	NS	NS	NS
Strain	<0.0001	NS	<0.0001	0.0003	<0.0001	<0.0001
Diet	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Indicates as a % of BW

[5] LYF = large yellow follicles on the ovary

Table 3 - 13. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on reproductive parameters in turkey hens at end of lay

	Ovary wt.		Oviduct wt.		Stroma wt.	Number LYF[5]
	(g)	(%)[4]	(g)	(%)[4]	(g)	
Strain X diet						
FF X CON	112.1	1.17	98.7	1.03	14.4	8.9
FF X HIGH	106.9	1.39	95.7	1.22	14.5	8.8
SF X CON	51.1	0.58	41.1	0.47	9.8	7.3
SF X HIGH	61.1	0.70	52.3	0.61	11.4	6.9
SEM	7.0	0.18	5.3	0.14	0.9	0.4
PSTIM X strain						
29 X FF	101.8	1.07	90.5	0.96	14.6	8.7
29 X SF	44.7	0.51	39.8	0.45	11.4	6.6
31 X FF	117.2	1.49	103.9	1.29	14.3	9.0
31 X SF	67.5	0.77	53.7	0.62	9.7	7.6
SEM	7.2	0.18	5.4	0.14	0.8	0.3
PSTIM X diet						
29 X CON	75.8	0.81	66.6	0.72	12.8	7.9
29 X HIGH	70.7	0.77	63.7	0.70	13.2	7.5
31 X CON	87.4	0.93	73.3	0.78	11.3	8.4
31 X HIGH	97.3	1.33	84.3	1.13	12.7	8.2
SEM	6.8	0.18	5.2	0.14	0.9	0.4
			P-values			
Sources of variation						
Strain X diet	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Indicates as a % of BW

[5] LYF = large yellow follicles on the ovary

Table 3 - 14. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on breast muscle conformation as determined by digital image analysis[4] in turkey hens at photostimulation (PSTIM)

	Whole breast[5]						Breast thickness[6]		
	Area (cm^2)	Length from right side (cm)	Length from left side (cm)	Keel (cm)	Middle (cm)	Widest (cm)	Thick (cm)	Middle (cm)	Thin (cm)
PSTIM									
29 wk	687.0	29.3	29.0	19.8	34.9	35.5	4.98	3.22	1.28
31 wk	712.9	29.6	29.6	20.3	35.4	35.9	4.99	3.26	1.26
SEM	4.4	0.2	0.1	0.2	0.2	0.2	0.06	0.06	0.04
Strain									
FF	710.9	29.8	29.7	20.2	35.4	35.9	5.06	3.26	1.27
SF	688.9	29.0	28.9	19.9	34.9	35.5	4.92	3.22	1.28
SEM	4.4	0.2	0.1	0.2	0.2	0.2	0.06	0.06	0.04
Diet									
CON	693.1	29.3	29.1	19.8	35.3	35.7	4.98	3.24	1.24
HIGH	706.8	29.5	29.5	20.3	35.0	35.7	4.99	3.24	1.30
SEM	4.4	0.2	0.1	0.2	0.2	0.2	0.06	0.06	0.04
	P-values								
Sources of variation									
PSTIM	NS	NS	NS	NS	NS	NS	NS	NS	NS
Strain	NS	NS	NS	NS	NS	NS	NS	NS	NS
Diet	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[5] Whole breast measurements: area = surface area of muscle; length from right side = length from the top of the anatomical left shoulder diagonally to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[6] Measurements of breast thickness: thick = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thin = thickness near the bottom of the breast

Table 3 - 15. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on breast muscle conformation as determined by digital image analysis[4] in turkey hens at photostimulation (PSTIM)

	Whole breast[5]						Breast thickness[6]		
	Area (cm^2)	Length from right side (cm)	Length from left side (cm)	Keel (cm)	Middle (cm)	Widest (cm)	Thick (cm)	Middle (cm)	Thin (cm)
Strain X diet									
FF X CON	701.1	29.5	29.3	19.9	35.6	35.9	4.98	3.27	1.25
FF X HIGH	720.8	30.1	30.1	20.5	35.2	35.9	5.13	3.26	1.28
SF X CON	685.1	29.2	29.0	19.8	35.0	35.4	4.98	3.22	1.23
SF X HIGH	692.7	28.9	28.9	20.0	34.8	35.6	4.86	3.23	1.32
SEM	6.2	0.3	0.2	0.3	0.3	0.3	0.09	0.09	0.05
PSTIM X strain									
29 X FF	707.5	29.9	29.7	20.1	35.4	36.0	5.06	3.25	1.30
29 X SF	666.5	28.7	28.3	19.5	34.4	35.1	4.91	3.20	1.27
31 X FF	714.4	29.8	29.7	20.3	35.4	35.8	5.05	3.28	1.24
31 X SF	711.4	29.4	29.6	20.3	35.3	35.9	4.92	3.25	1.28
SEM	6.2	0.3	0.2	0.3	0.3	0.3	0.09	0.09	0.05
PSTIM X diet									
29 X CON	681.2	29.1	28.9	19.5	35.1	35.4	4.99	3.30	1.24
29 X HIGH	692.8	29.5	29.1	20.0	34.8	35.6	4.98	3.15	1.33
31 X CON	705.0	29.6	29.4	20.1	35.5	35.9	4.97	3.19	1.25
31 X HIGH	720.8	29.5	29.9	20.5	35.3	35.8	5.01	3.34	1.27
SEM	6.2	0.3	0.2	0.3	0.3	0.3	0.09	0.09	0.05
P-values									
Sources of variation									
Strain X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[5] Whole breast measurements: area = surface area of muscle; length from right side = length from the top of the anatomical left shoulder diagonally to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[6] Measurements of breast thickness: thick = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thin = thickness near the bottom of the breast

Table 3 - 16. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on breast muscle conformation as determined by digital image analysis[4] in turkey hens at sexual maturity

	Whole breast[5]						Breast thickness[6]		
	Area (cm^2)	Length from right side (cm)	Length from left side (cm)	Keel (cm)	Middle (cm)	Widest (cm)	Thick (cm)	Middle (cm)	Thin (cm)
PSTIM									
29 wk	617.6	28.0	27.7	20.6	32.7	33.1	4.57	2.53	0.91
31 wk	634.5	28.4	28.2	20.7	33.0	33.5	4.70	2.45	0.85
SEM	10.9	0.3	0.3	0.3	0.4	0.4	0.10	0.10	0.04
Strain									
FF	638.2	28.5	28.3	20.7	33.2	33.5	4.68	2.46	0.84
SF	613.9	27.9	27.6	20.6	32.5	33.0	4.59	2.52	0.92
SEM	11.1	0.3	0.3	0.3	0.4	0.4	0.094	0.094	0.04
Diet									
CON	625.2	28.1	28.0	20.4	32.9	33.4	4.59	2.42	0.85
HIGH	626.9	28.3	27.9	20.8	32.8	33.1	4.67	2.56	0.91
SEM	10.8	0.3	0.3	0.3	0.4	0.4	0.10	0.09	0.04
	P-values								
Sources of variation									
PSTIM	NS	NS	NS	NS	NS	NS	NS	NS	NS
Strain	NS	NS	NS	NS	NS	NS	NS	NS	NS
Diet	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[5] Whole breast measurements: area = surface area of muscle; length from right side = length from the top of the anatomical left shoulder diagonally to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[6] Measurements of breast thickness: thick = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thin = thickness near the bottom of the breast

Table 3 - 17. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on breast muscle conformation as determined by digital image analysis[4] in turkey hens at sexual maturity

	Whole breast[5]						Breast thickness[6]		
	Area	Length from right side	Length from left side	Keel	Middle	Widest	Thick	Middle	Thin
	(cm^2)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
Strain X diet									
FF X CON	636.0	28.4	28.4	20.4	33.3	33.7	4.67	2.43	0.78
FF X HIGH	640.4	28.6	28.3	21.0	33.0	33.4	4.70	2.49	0.90
SF X CON	614.5	27.9	27.6	20.4	32.6	33.0	4.52	2.42	0.91
SF X HIGH	613.3	28.0	27.5	20.7	32.5	32.9	4.65	2.63	0.93
SEM	15.2	0.4	0.5	0.4	0.6	0.5	0.15	0.13	0.06
PSTIM X strain									
29 X FF	632.8	28.3	28.1	20.6	33.1	33.5	4.66	2.58	0.91
29 X SF	602.4	27.8	27.3	20.6	32.2	32.6	4.48	2.48	0.92
31 X FF	643.6	28.6	28.6	20.8	33.2	33.5	4.71	2.33	0.77
31 X SF	625.4	28.1	27.8	20.5	32.9	33.4	4.69	2.56	0.93
SEM	15.7	0.4	0.5	0.4	0.5	0.5	0.14	0.13	0.06
PSTIM X diet									
29 X CON	624.1	28.2	27.9	20.5	32.7	33.2	4.53	2.49	0.88
29 X HIGH	611.1	27.9	27.5	20.6	32.6	32.9	4.60	2.57	0.94
31 X CON	626.4	28.1	28.1	20.3	33.1	33.5	4.66	2.35	0.81
31 X HIGH	642.7	28.7	28.3	21.0	33.0	33.4	4.74	2.54	0.89
SEM	15.7	0.4	0.5	0.4	0.5	0.5	0.15	0.13	0.06
	P-values								
Sources of variation									
Strain X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[5] Whole breast measurements: area = surface area of muscle; length from right side = length from the top of the anatomical left shoulder diagonally to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[6] Measurements of breast thickness: thick = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thin = thickness near the bottom of the breast

Table 3 - 18. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on breast muscle conformation as determined by digital image analysis[4] in turkey hens at end of lay

	Whole breast[5]						Breast thickness[6]		
	Area (cm^2)	Length from right side (cm)	Length from left side (cm)	Keel (cm)	Middle (cm)	Widest (cm)	Thick (cm)	Middle (cm)	Thin (cm)
PSTIM									
29 wk	559.8	27.3	27.1	20.1	30.5	30.9	4.81	2.80	0.98[b]
31 wk	564.6	27.4	27.7	20.4	29.7	30.2	4.92	3.05	1.32[a]
SEM	4.0	0.1	0.1	0.1	0.2	0.2	0.07	0.06	0.04
Strain									
FF	572.9	27.8	27.7	20.4	30.2	30.8	4.79	2.79	1.08[b]
SF	551.4	26.9	27.0	20.0	29.9	30.3	4.95	3.06	1.23[a]
SEM	3.9	0.1	0.1	0.1	0.2	0.2	0.07	0.06	0.04
Diet									
CON	560.1	27.2	27.3	20.2	30.1	30.5	4.91	2.98	1.13
HIGH	564.2	27.5	27.5	20.3	30.0	30.6	4.83	2.87	1.18
SEM	4.0	0.1	0.1	0.1	0.2	0.2	0.07	0.06	0.04
SEM	5.8	0.1	0.2	0.2	0.2	0.2	0.10	0.08	0.06
	P-values								
Sources of variation									
PSTIM	NS	NS	NS	NS	NS	NS	NS	NS	<0.0001
Strain	NS	NS	NS	NS	NS	NS	NS	NS	0.0156
Diet	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[5] Whole breast measurements: area = surface area of muscle; length from right side = length from the top of the anatomical left shoulder diagonally to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[6] Measurements of breast thickness: thick = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thin = thickness near the bottom of the breast

Table 3 - 19. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on breast muscle conformation as determined by digital image analysis[4] in turkey hens at end of lay

	Whole breast[5]					Breast thickness[6]		
	Area (cm^2)	Length from right side (cm)	Length from left side (cm)	Keel (cm)	Middle (cm)	Widest (cm)	Thick (cm)	Middle (cm)	Thin (cm)
Strain X diet									
FF X CON	567.1	27.5	27.5	20.2	30.3	30.7	4.82	2.87	1.06
FF X HIGH	578.8	28.1	28.0	20.6	30.2	30.9	4.75	2.71	1.09
SF X CON	553.2	27.0	27.1	20.2	29.9	30.3	4.99	3.09	1.19
SF X HIGH	549.7	26.8	26.9	19.9	29.9	30.4	4.90	3.03	1.26
SEM	5.5	0.1	0.2	0.2	0.2	0.2	0.09	0.09	0.06
PSTIM X strain									
29 X FF	564.0	27.6	27.3	20.2	30.5	31.0	4.68	2.66	0.90
29 X SF	555.6	27.0	26.8	19.9	30.5	30.8	4.95	2.93	1.07
31 X FF	581.9	28.0	28.2	20.6	30.0	30.6	4.89	2.92	1.25
31 X SF	547.3	26.8	27.1	20.1	29.3	29.8	4.95	3.19	1.39
SEM	5.7	0.1	0.2	0.2	0.2	0.2	0.09	0.08	0.06
PSTIM X diet									
29 X CON	555.9	27.2	26.9	20.0	30.4	30.8	4.83	2.85	0.98
29 X HIGH	563.7	27.5	27.2	20.2	30.5	31.0	4.80	2.75	0.98
31 X CON	564.3	27.3	27.6	20.4	29.8	30.2	4.99	3.12	1.27
31 X HIGH	564.8	27.5	27.7	20.3	29.5	30.2	4.85	2.99	1.37
SEM	5.8	0.1	0.2	0.2	0.2	0.2	0.10	0.08	0.06
P-values									
Sources of variation									
Strain X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[5] Whole breast measurements: area = surface area of muscle; length from right side = length from the top of the anatomical left shoulder diagonally downwards to the posterior end of the P. major; length of left side = length from the top of the anatomical right shoulder diagonally downwards to the posterior end of the P. major; keel = length corresponding to where P. major was attached to the sternum; middle = line corresponding to width at midpoint of breast; widest = line corresponding to width at widest point of breast.

[6] Measurements of breast thickness: thick = uppermost thickness near top of anatomical left half of breast; middle = thickness near the middle of anatomical left half of breast; thin = thickness near the bottom of the breast

Table 3 - 20. Effect of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on egg production parameters in turkey hens 30 to 56 wk of age

			Egg quality[6]										
	Prime sequence length[4] (d)	Total eggs[5]	Settable	Soft-shelled	No shell	Double-yolked	Abnormal shell	Number of pauses	Number of sequences	Avg. sequence length (d)	Avg. pause length (d)	Age at last egg laid (wk)	Number of ovulations[7]
PSTIM													
29 wk	10.3	79.6	78.2	0.60	0.50	0.24[a]	0.030	24.3	26.1	3.3	1.8	46.9	79.8
31 wk	9.5	77.5	76.8	0.31	0.29	0.08[b]	0.041	23.9	25.7	3.2	1.5	48.2	77.6
SEM	0.4	3.0	3.0	0.16	0.086	0.05	0.016	1.2	1.2	0.1	0.1	0.7	3.1
Strain													
FF	11.9[a]	98.9[a]	97.2[a]	0.71[a]	0.66[a]	0.30[a]	0.029	26.0	27.7	3.8[a]	1.5	49.9[a]	99.2[a]
SF	8.0[b]	58.2[b]	57.9[b]	0.19[b]	0.13[b]	0.02[b]	0.043	22.1	24.0	2.7[b]	1.8	45.2[b]	58.3[b]
SEM	0.3	3.0	3.0	0.17	0.088	0.049	0.016	1.2	1.2	0.1	0.1	0.8	3.0
Diet													
CON	9.9	76.2	75.0	0.56	0.43	0.19	0.022	23.0	24.8	3.3	1.9[a]	47.4	76.4
HIGH	10.0	80.9	80.0	0.35	0.37	0.14	0.049	25.2	27.0	3.2	1.4[b]	47.7	81.1
SEM	0.4	3.0	3.0	0.17	0.086	0.048	0.015	1.2	1.2	0.1	0.1	0.8	3.0
	P-values												
Sources of variation													
PSTIM	NS	NS	NS	NS	NS	0.0258	NS	NS	NS	NS	NS	NS	NS
Strain	<0.0001	<0.0001	<0.0001	NS	<0.0001	<0.0001	NS	NS	NS	<0.0001	NS	<0.0001	<0.0001
Diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0194	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Prime sequence length = longest sequence of eggs laid

[5] Total eggs = number of eggs laid per hen (including settable and defective eggs)

[6] Egg quality: settable = number of eggs with a single yolk and a hard intact shell; soft-shelled = number of eggs with a non-calcified shell; no shell = number of eggs laid without a shell; double-yolked = number of eggs laid with more than one yolk (verified at weighing by cracking open); abnormal shell = number of eggs laid that were under 60 g or had shell abnormalities

[7] Number of ovulations = number of yolks in both defective and normal eggs laid (i.e. a double-yolked egg counted as one defective egg but two ovulations

Table 3 - 21. Interactions of diet (CON or HIGH)[1], strain (FF or SF)[2] and age at photostimulation (29 or 31 wk)[3] on egg production parameters in turkey hens 30 to 56 wk of age

			Egg quality[6]										
	Prime sequence length[4] (d)	Total eggs[5]	Settable	Soft-shelled	No shell	Double-yolked	Abnormal shell	Number of pauses	Number of sequences	Avg. sequence length (d)	Avg. pause length (d)	Age at last egg laid (wk)	Number of ovulations[7]
Strain X diet													
FF X CON	11.8	98.3	96.3	0.95	0.70	0.35[a]	0.034	26.0	27.7	3.8	1.7	50.5	98.6
FF X HIGH	11.9	99.5	98.1	0.48	0.62	0.26[a]	0.024	26.1	27.7	3.8	1.2	49.4	99.7
SF X CON	7.9	54.1	53.7	0.17	0.15	0.02[b]	0.010	19.9	21.8	2.8	2.0	44.3	54.1
SF X HIGH	8.0	62.4	62.0	0.21	0.11	0.01[b]	0.075	24.3	26.2	2.6	1.7	46.1	62.4
SEM	0.5	4.4	4.2	0.24	0.13	0.07	0.021	1.6	1.7	0.1	0.2	1.1	4.2
PSTIM X strain													
29 X FF	12.5	102.2	99.9	0.96	0.88	0.46	0.036	26.7	28.5	3.8	1.6	50.0	102.7
29 X SF	8.1	57.0	56.6	0.24	0.13	0.01	0.025	21.8	23.7	2.9	2.0	43.8	57.0
31 X FF	11.2	95.6	94.5	0.47	0.45	0.15	0.022	25.3	27.0	3.7	1.3	49.9	95.7
31 X SF	7.8	59.5	59.1	0.15	0.14	0.02	0.060	22.5	24.4	2.6	1.7	46.5	59.5
SEM	0.5	4.4	4.3	0.23	0.12	0.07	0.022	1.7	1.7	0.1	0.2	1.1	4.2
PSTIM X diet													
29 X CON	10.3	76.6	75.0	0.80	0.54	0.27	0.011	22.7	24.5	3.4	2.2	46.5	76.9
29 X HIGH	10.3	82.6	81.5	0.39	0.46	0.21	0.050	25.8	27.6	3.2	1.4	47.2	82.8
31 X CON	9.4	75.8	75.0	0.32	0.31	0.10	0.033	23.3	25.1	3.2	1.6	48.2	75.9
31 X HIGH	9.6	79.3	78.6	0.30	0.27	0.07	0.049	24.6	26.3	3.2	1.5	48.2	79.3
SEM	0.5	4.4	4.3	0.23	0.12	0.07	0.022	1.6	1.7	1.5	0.2	1.1	4.2
	P-values												
Sources of variation													
Strain X diet	NS	NS	NS	NS	NS	0.0171	NS	NS	NS	NS	NS	NS	NS
PSTIM X strain	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PSTIM X diet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a,b] Means within a column with no common superscript differ significantly ($P < 0.05$)

[1] Diets: CON = formulated as a standard commercial poult diet to meet breeder-recommended nutrient levels, HIGH = formulated to contain at least 8%, and not more than 15% more protein, including essential amino acids, than the CON diet

[2] FF = fast-feathering, SF = slow-feathering

[3] 29 = 29 wk old at photostimulation, 31 = 31 wk old at photostimulation

[4] Prime sequence length = longest sequence of eggs laid

[5] Total eggs = number of eggs laid per hen (including settable and defective eggs)

[6] Egg quality: settable = number of eggs with a single yolk and a hard intact shell; soft-shelled = number of eggs with a non-calcified shell; no shell = number of eggs laid without a shell; double-yolked = number of eggs laid with more than one yolk (verified at weighing by cracking open); abnormal shell = number of eggs laid that were under 60 g or had shell abnormalities

[7] Number of ovulations = number of yolks in both defective and normal eggs laid (i.e. a double-yolked egg counted as one defective egg but two ovulations

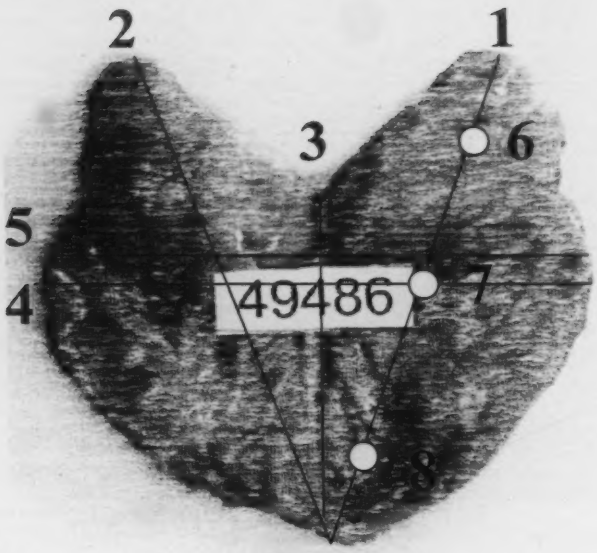


Figure 3 - 1. Digital[1] measurements[2] of pectoralis major (P. major).

[1] software program Northern Exposure® by Empix Imaging Inc,. Missisauga, ON, Canada, L5L 5M6

[2] Whole breast measurements: area = surface area of P. major; line1 = length from the tip of the anatomical left shoulder diagonally to the posterior end of the breast where P. major was attached to the sternum; line 2 = length from the tip of the anatomical right shoulder diagonally to the posterior end of the breast where P. major was attached to the sternum; line 3 = length corresponding to where P. major was attached to the sternum; line 4 = line corresponding to width at midpoint of breast; line 5 = line corresponding to width at widest point of breast; point 6 = uppermost thickness near the top anatomical left half of the P. major; point 7 = thickness of the muscle at the approximate middle of the anatomical left half of the P. major; point 8 = thickness of the muscle near the bottom of the P. major.

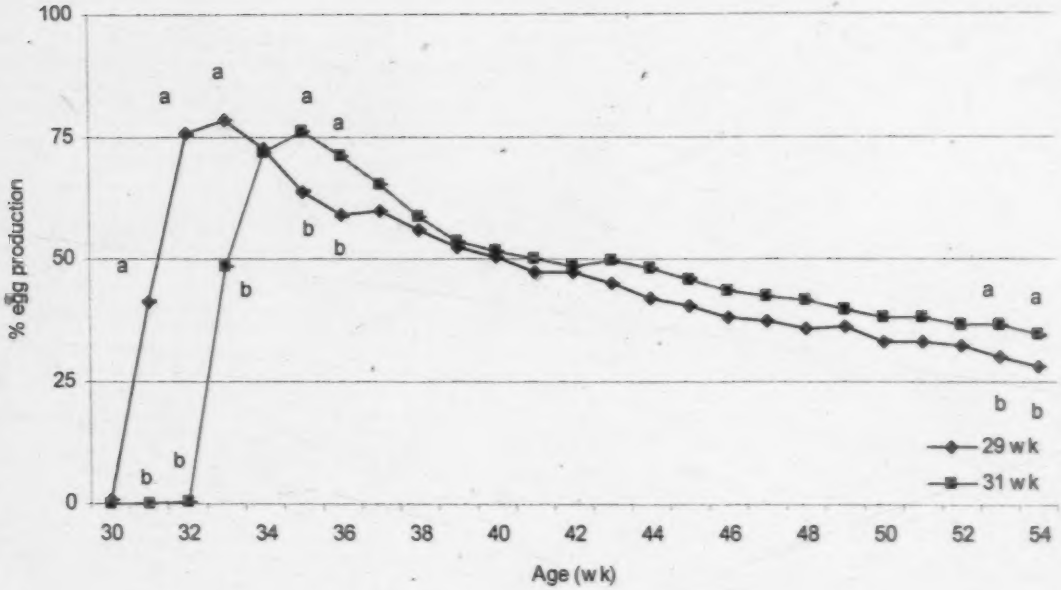


Figure 3 - 2. Effect of age at photostimulation (29 or 31 wk) on % egg production (± SEM) in turkey hens from 30 to 56 wk of age. [a,b] Means within an age with no common superscript differ significantly ($P < 0.05$).

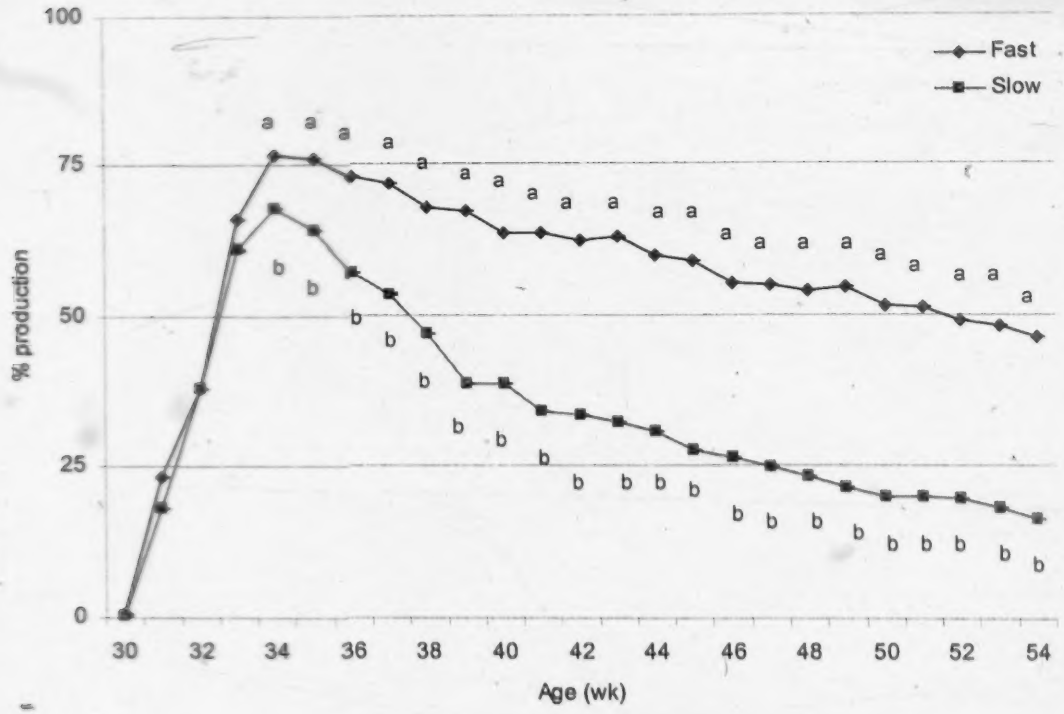


Figure 3 - 3. Effect of strain (FF or SF) on % egg production (± SEM) in turkey hens from 30 to 56 wk of age. [a,b] Means within an age with no common superscript differ significantly ($P < 0.05$).

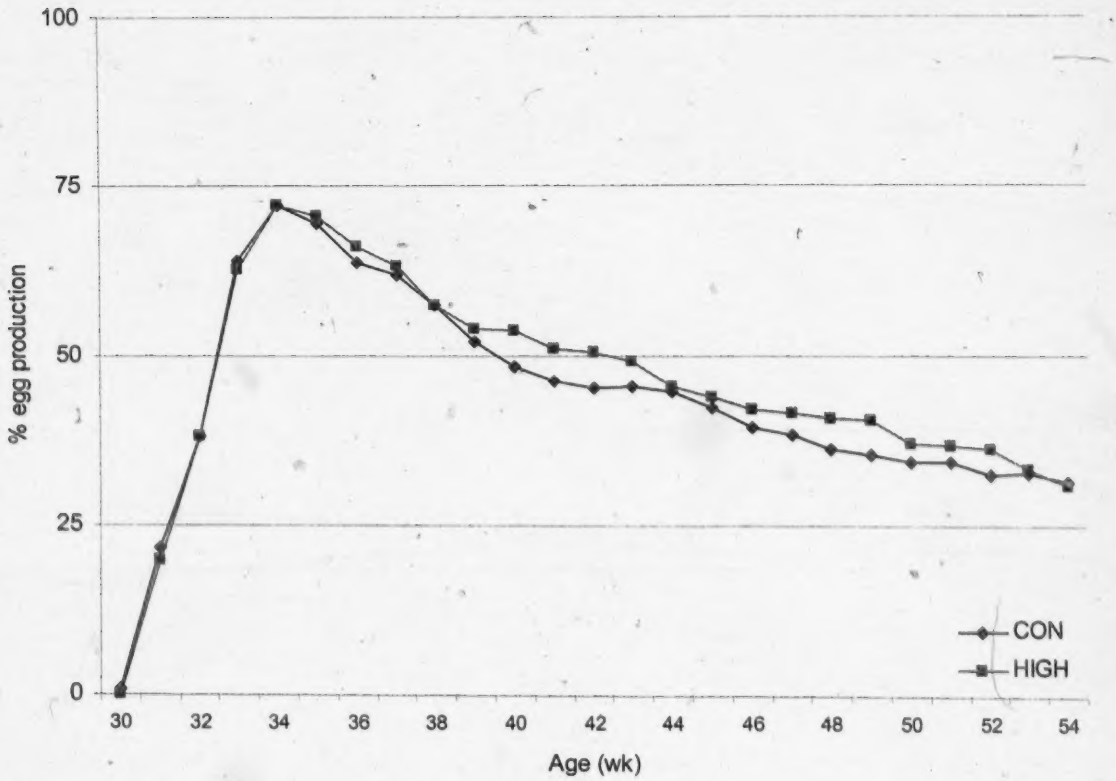


Figure 3 - 4. Effect of diet (CON or HIGH) on % egg production (± SEM) in turkey hens from 30 to 56 wk of age. [a,b] Means within an age with no common superscript differ significantly ($P < 0.05$).

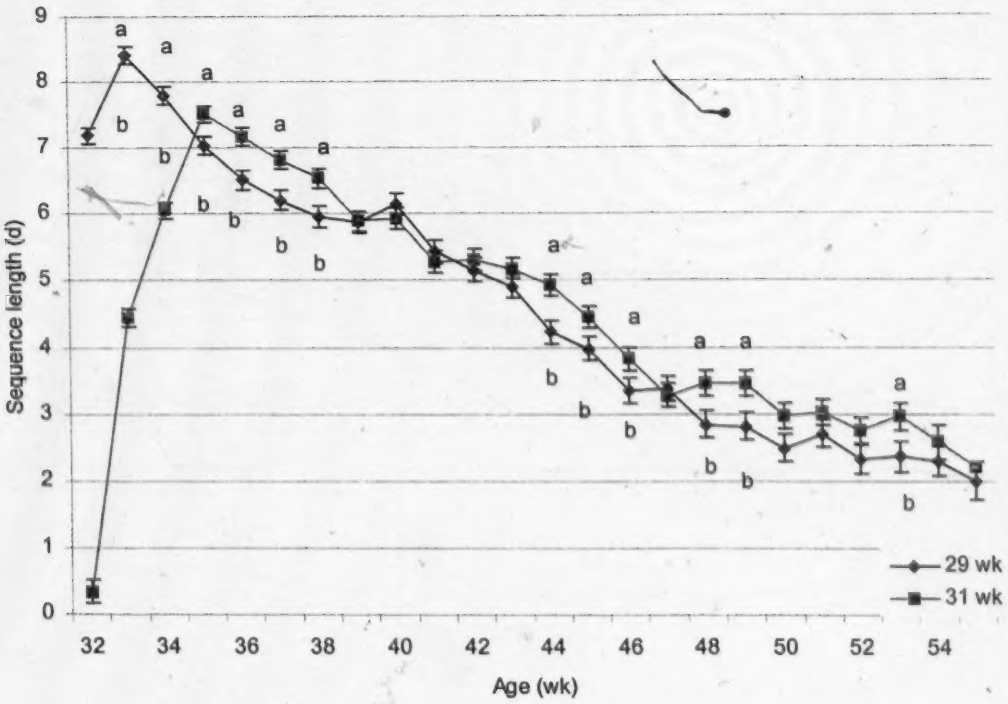


Figure 3 - 5. Effect of age at photostimulation (29 or 31 wk) on sequence length in days (± SEM) in turkey hens from 32 to 56 wk of age. [a,b] Means within an age with no common superscript differ significantly ($P < 0.05$).

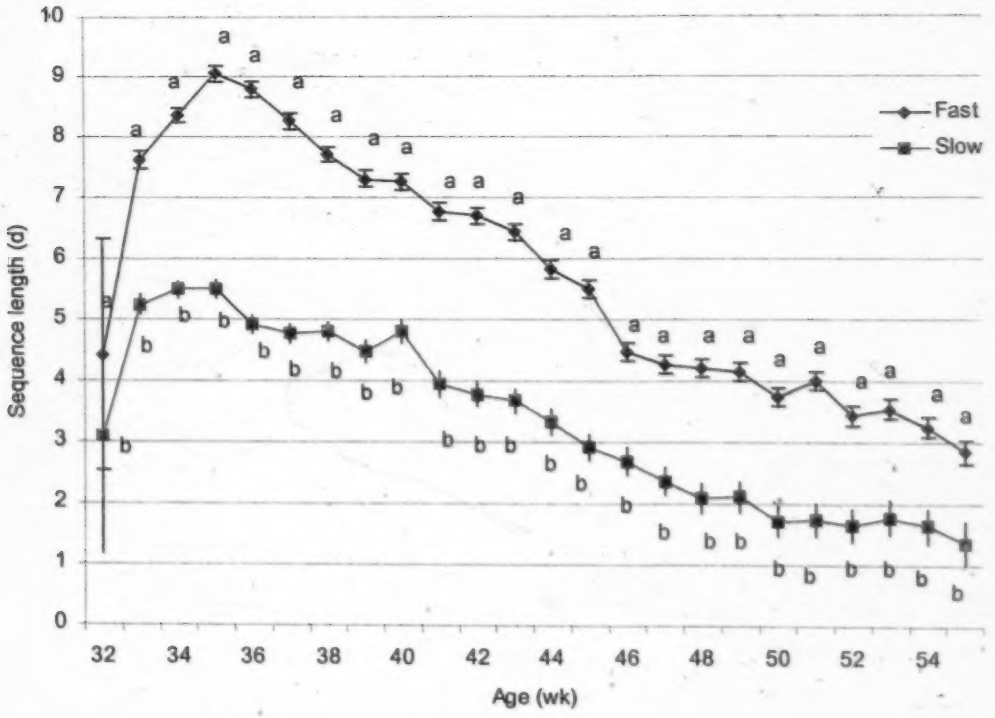


Figure 3 - 6. Effect of strain (FF or SF) on sequence length in days (± SEM) in turkey hens from 32 to 56 wk of age. [a,b] Means within an age with no common superscript differ significantly ($P < 0.05$).

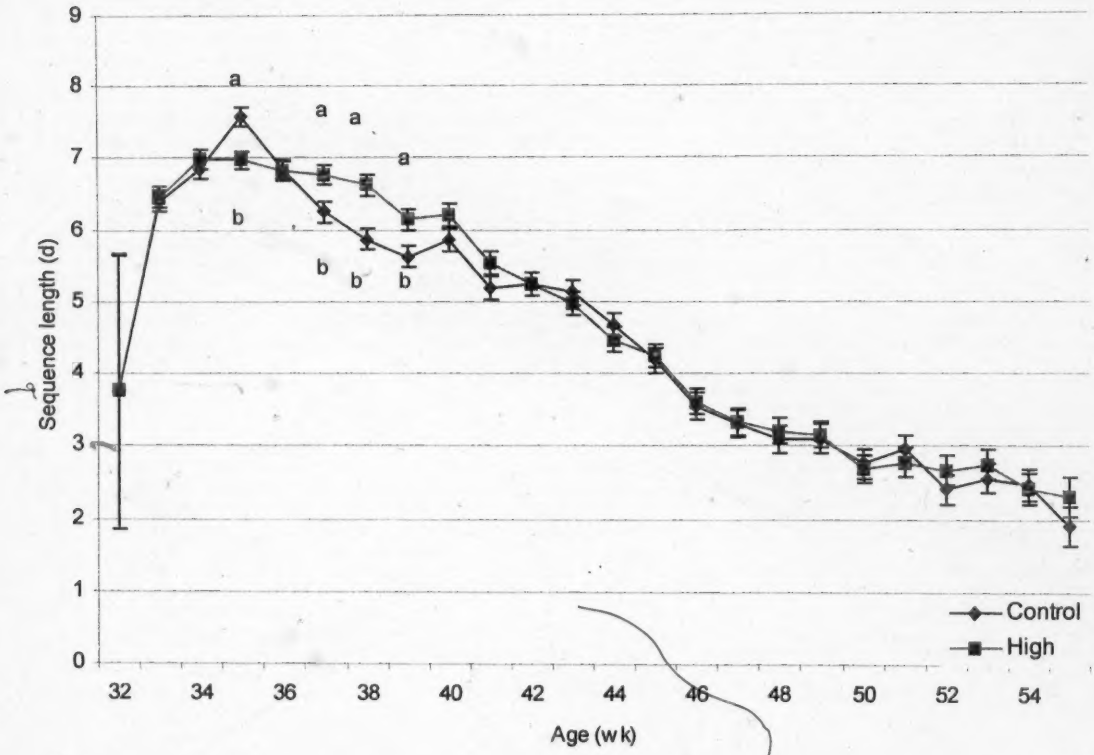


Figure 3 - 7. Effect of diet (CON or HIGH) on sequence length in days (± SEM) in turkey hens from 32 to 56 wk of age. [a,b] Means within an age with no common superscript differ significantly ($P < 0.05$).

4.0 GENERAL DISCUSSION

The turkey industry comprises a relevant portion of Canada's poultry industry. Because turkeys have a longer production cycle than chickens, management techniques that improve production efficiency are valuable to the industry. One area that remains to be improved in turkeys is bird sexing, as sex-separate rearing can improve feed efficiency and facilitates the raising of birds to different market ages. A technique used to increase speed and accuracy of sexing in commercial chickens is feather-sexing, based on the use of a slow-feathering (SF) gene. Currently, all turkeys that are sexed are vent-sexed because a commercial feather-sexable line has not been developed. The focus of this work was to characterize the pleiotropic effects of the slow-feathering gene in breeder turkeys to determine the viability of feather-sexing in turkeys as a way to increase efficiency in the production chain. The SF turkeys were assessed according to commercial production traits, as these are the traits that need to be preserved in order to have a marketable product.

1. In the rearing portion of this trial, the growth and carcass morphology of SF turkeys was assessed compared to fast-feathering (FF), or commercial, turkeys. The response of both strains to increased nutrient density was also evaluated by feeding a commercial diet and a diet that was 10% higher in protein and energy. Strain differences were apparent with regard to BW and feather cover during rearing, as observed in previous industry trials with SF poults (Sikur, Thesis: Chapter 2). The SF poults were shown to have a different approach to nutrient partitioning, as BW was reduced but breast muscle weight was increased compared to FF poults. Increasing nutrient density was a successful method of improving BW gain and feather cover to

12 wk in SF poults. A large degree of variability was observed with regard to BW and feather cover in SF birds. This indicates that while increasing nutrient density was beneficial, this approach may result in increased feed costs on a commercial scale. Greater improvement may be achieved through continued selection for desireable production traits.

2. Observations on the turkeys described above were carried through to the reproductive cycle. Carcass morphology and reproductive efficiency was characterized in SF and FF turkey hens. The effects of increased nutrient density as well as delayed age at photostimulation, previously shown to have benefits in bird reproduction, were investigated in both strains. Previous industry trials reported decreased egg production in SF hens compared to commercial hens. The SF hens had reduced BW and egg production compared to commercial birds during lay (Sikur, Thesis: Chapter 3). As expected, nutrient density had few significant effects after the growth phase. Delaying photostimulation was successful in increasing BW and egg production as a strategy to increase body reserves of SF hens before sexual maturity. However, egg production of SF hens was markedly below that of the commercial hens. This was disappointing because it was thought that incorporation of the SF gene into a commercial line and subsequent back-crossing would dilute the negative effects associated with reproduction previously seen in SF turkeys. Again, wide variability was noted with regard to egg production in SF hens, indicating that , as with growth, continued selection for production-related traits may overcome the less desirable effects associated with the SF phenotype. It is important to note that considerable

improvements in nesting behavior and egg production have been made since the incorporation of the gene into a commercial turkey line.

This generation of SF birds shows promise for future research. Although not as much progress in terms of reproductive efficiency was made as was hoped through genetic selection (T. F. Savage, Oregon State University, Oregon, U. S. A., personal communication, February 2003), the level of divergence seen in individual bird traits such as feather cover and egg production is encouraging. The chicken industry has overcome most of the difficulties associated with this gene. Research continues to look at broiler chicken skin strength with respect to carcass quality. With continued research into characterization and genetic selection for growth, feather cover, reproductive traits and carcass quality of these birds, a marketable feather-sexable turkey line is a possibility.

APPENDIX A

Training birds to trap nests

Two trap nest boxes per pen were provided at photostimulation, and trap nest doors were initially tied open for 4 wk after photostimulation to encourage nest usage by hens. Carpet on the nest bottom and a maintained level of wood shavings provided warmth that encouraged hens to use the nests. Some birds were able to fly on and off the nest boxes, and in and out of the nests through the holes in the top of the nest boxes where eggs were collected. This activity put the birds at a high risk for injury. To prevent this, two modifications were made to the nest boxes in pens where this was a problem. Wood pieces approximately 1" thick and 2" wide were secured over the holes in the tops of the nests. As well, sheets of thick white plastic that were as long as the nests and approximately 3' high were secured about 2' above the pen wall behind the nests to form a roof. Hens were palpated twice daily for the presence of an egg in the oviduct 2 wk after photostimulation. If a hard-shelled egg was detected, this was indicated on the data sheet by a large circle under the appropriate day and across from the correct bird number, and that bird was placed in a nest with the door closed and monitored at 30-min intervals until the egg was laid. The bird was then released from the nest and the egg removed from the nest. The bird identification, pen number and approximate time of lay were recorded on each egg and on the pen's data sheet. This information, as well as the egg quality (using the letter system) and egg weight, was recorded on separate data sheets. On average, a bird in normal production laid an egg about every 26 hours until the end of the sequence. Using the information from the pen data sheets on approximate time of lay from the previous day and regular palpations, the approximate time of lay for most birds could be determined. A month after photostimulation, most birds had learned to lay in the

nest. The nest doors were then closed in the evening when lights went off, and opened again the following morning.

Daily schedule for trap nesting

Once flock egg production fully commenced, egg collections were performed on an hourly basis for 12 h each day throughout the laying cycle. Daily, nest box doors were opened and palpations were performed approximately 2 h after the lights came on. This allowed enough time to identify birds that were ready to lay early in the morning and minimized the number of unidentified eggs, usually those that were laid on the floor. Palpations were done again approximately 3 to 4 h before the lights went off on birds that were in production to increase data accuracy. The second palpation also allowed the technician to identify and prepare if a large number of birds were due to lay early the next morning.

At first, nest doors were opened and any bird was allowed into the nest. It was found that some birds were using the nests to escape from other birds, or preferred to sit on the nest for long periods, whether or not they were in lay. Because the pen size limited nest space, a bird that had laid an egg in the nest was released or gently pushed out and the egg removed from the pen by a technician. From the pen data sheets, the next bird that was due to lay in approximately the next hour was shown to the nest and entered with usually little or no persuasion. Trap nest doors were closed at the end of the day.

Unidentified or missing eggs

Occasionally eggs were found on the floor or in the nest with no information as to which hen it came from. Birds that were expected to lay were sometimes found to have no hard-shelled egg in the oviduct. The protocol was to first scan the pen data sheets to

ensure that all information from the eggs laid previously and the palpations that day had been recorded correctly. It was easy to look back over the current week or previous week to see the laying patterns of the birds in that pen once the flock had entered full production and determine if an error had been made during recording. The next step was palpate the birds in the pen to confirm which birds still had a hard-shelled egg in their oviduct. This step usually yielded the information as to which bird had laid the unidentified egg. Often, an unidentified egg with a poor or deformed shell was one that was laid earlier than expected and hence was laid on the floor before the technician could show the bird to the nest. As an additional step, or to differentiate between two unidentified eggs laid in the same pen at around the same time, an "egg library" or samples of eggs laid from each bird was kept to compare size, shape, color and pattern. In most cases, eggs laid from specific hens could be identified according to several of these characteristics, as well as egg weight.

If an egg could not immediately be identified, its pen number and weight were still recorded, and the information transferred to the data sheet. The egg was kept for a few days to compare other eggs from the pen, especially if it was suspected that a bird that went out of lay and was coming back in. As well, a few birds laid characteristically poor eggs that were often broken and hidden in the litter before the technician could find them. A good practice by the technician was to disturb the litter regularly or observe when the pens were being cleaned for the presence of still moist, or dry, paper-textured soft-shelled eggs that were laid on the floor and mixed into the litter. A moist broken soft-shelled egg with yolk still on it was likely laid in the time shortly preceding the last pen check and the hen could still have a possibility of being identified. While these

practices did not conclusively lead to the desired hen information in every instance, it clarified some of the irregular laying patterns inherent in biological systems.

The key to minimizing the number of unidentified eggs was to check each pen often, especially at the beginning of production and during the "busy" times of day, characteristically when a large number of birds were expected to lay in a short time. The afternoon palpation on birds in production was useful because it could be performed quickly, confirmed the presence of eggs not yet laid, and provided information about which birds were expected to lay the following day. Behavioral observation was also a useful tool to identify which birds were ready to lay. A bird that was usually within a half hour of laying an egg and that had been trained to the nest would often pace around the nest doors, pushing on the doors to be let in. However, a few individual birds preferred to lay on the floor, and would withhold the egg if forced into the nest, laying the egg on the floor immediately after being released from the nest.

It is obvious from the preceding explanation that every effort was made to ensure as much accuracy as possible in the data collection during the laying period.

Sample Data Sheet

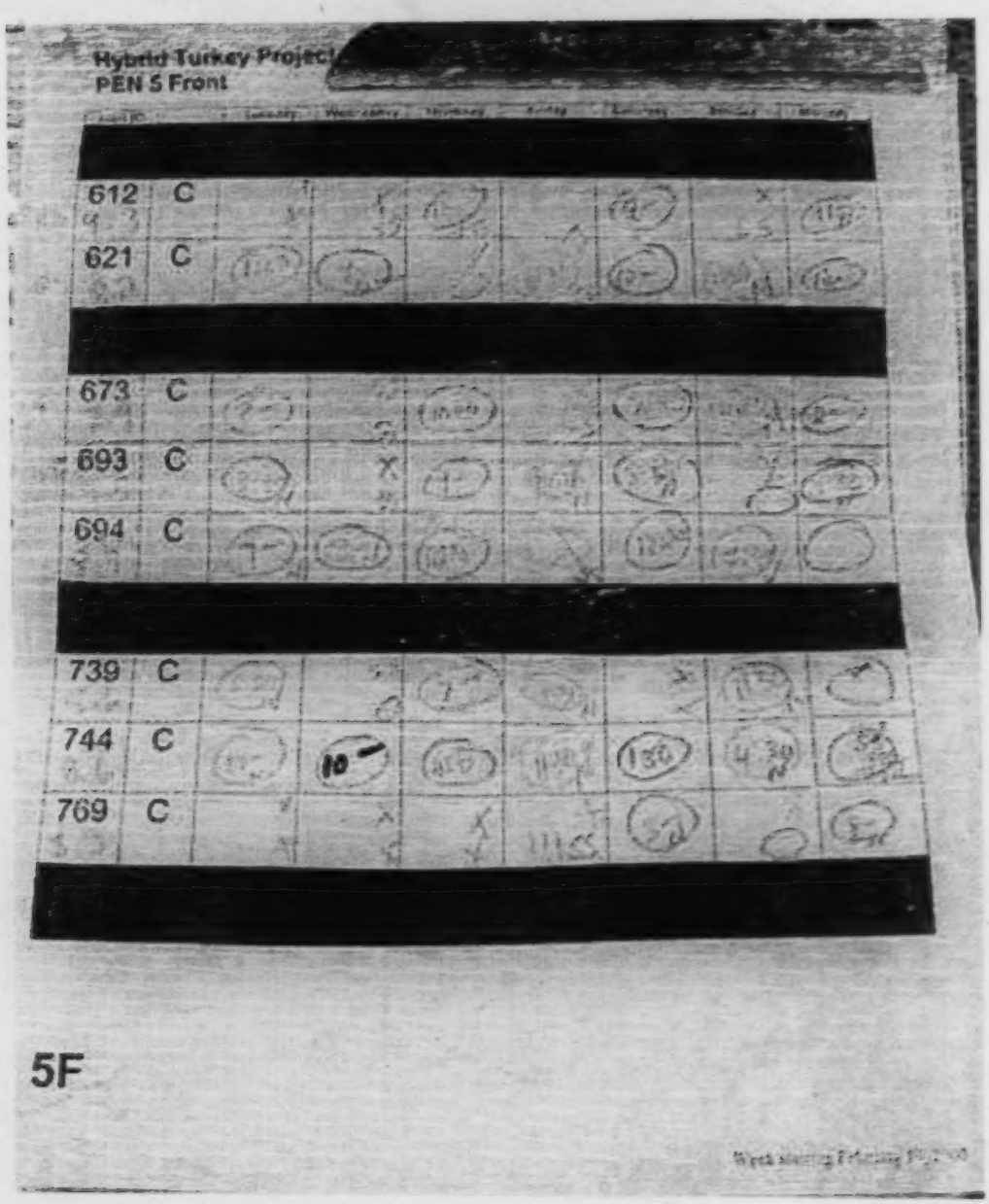
Project _____ Week __ Starting Tuesday _____

Pen ID _____ Treatment Description _____

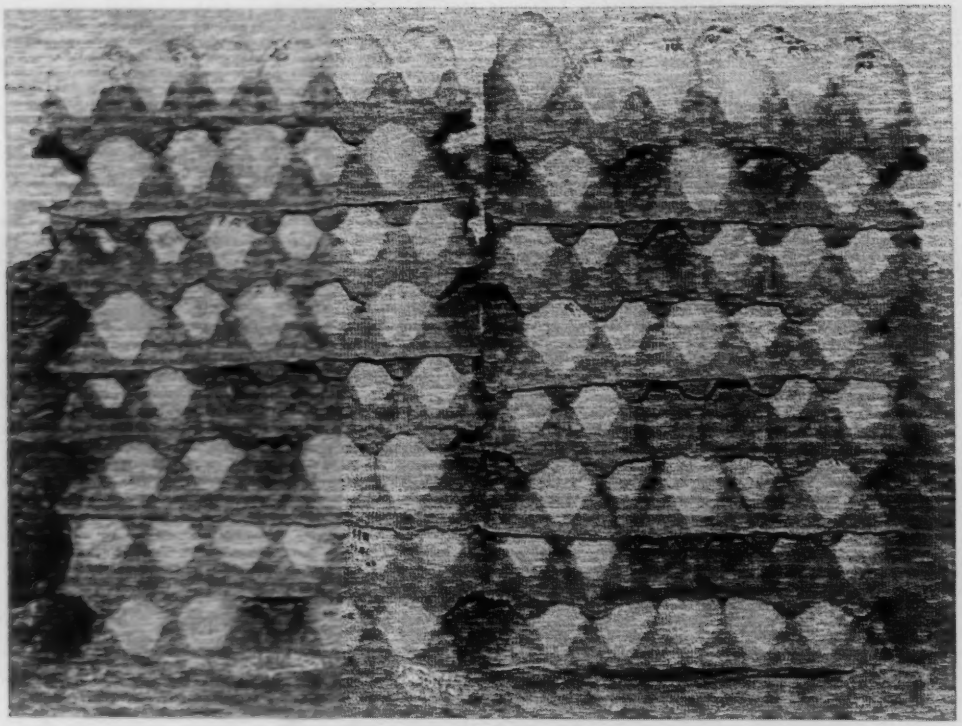
Hen ID	Fate	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday

Pen ID ____

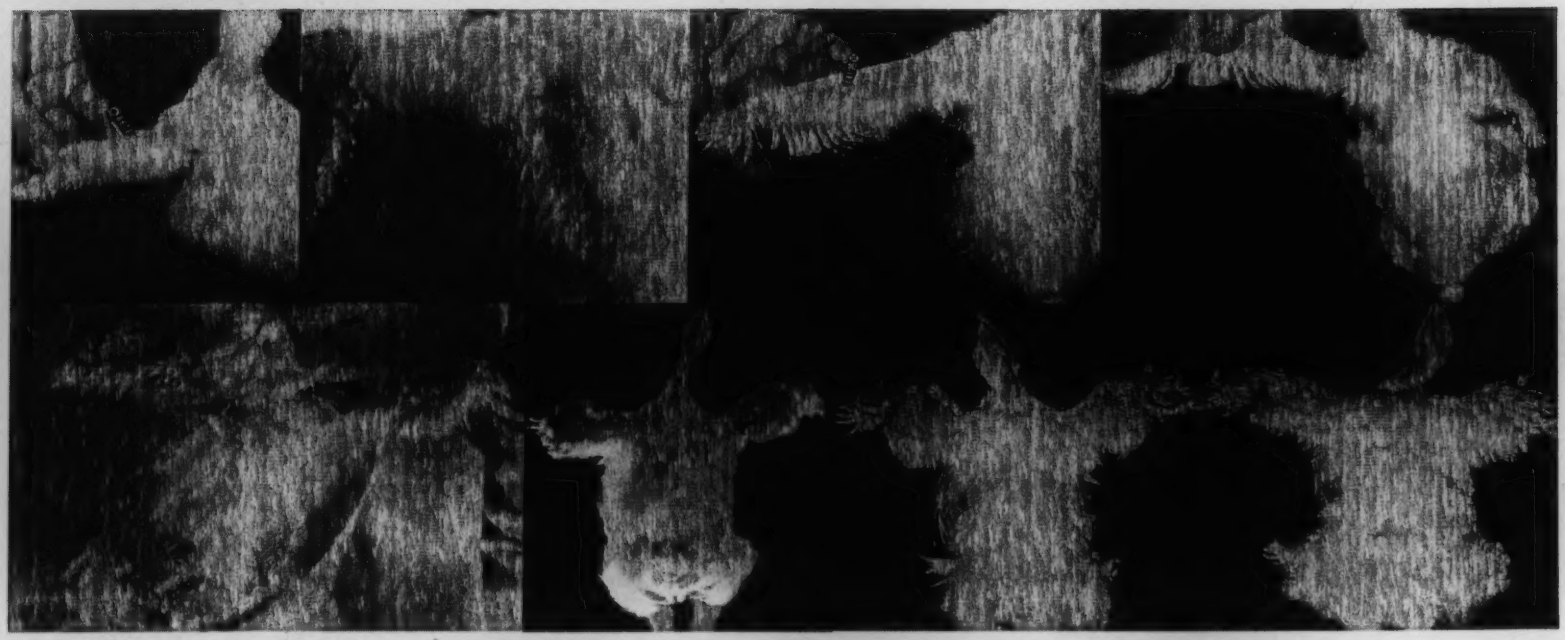
Sample Completed Data Sheet



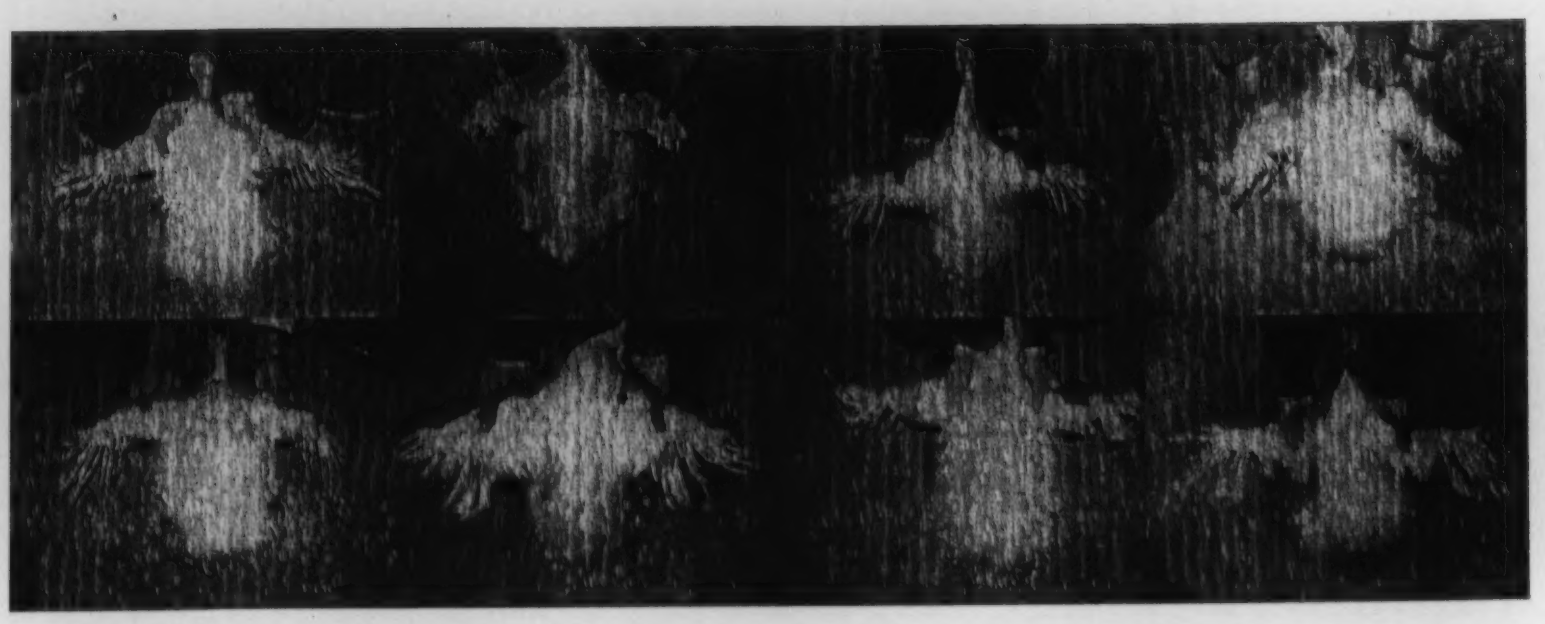
Egg Library



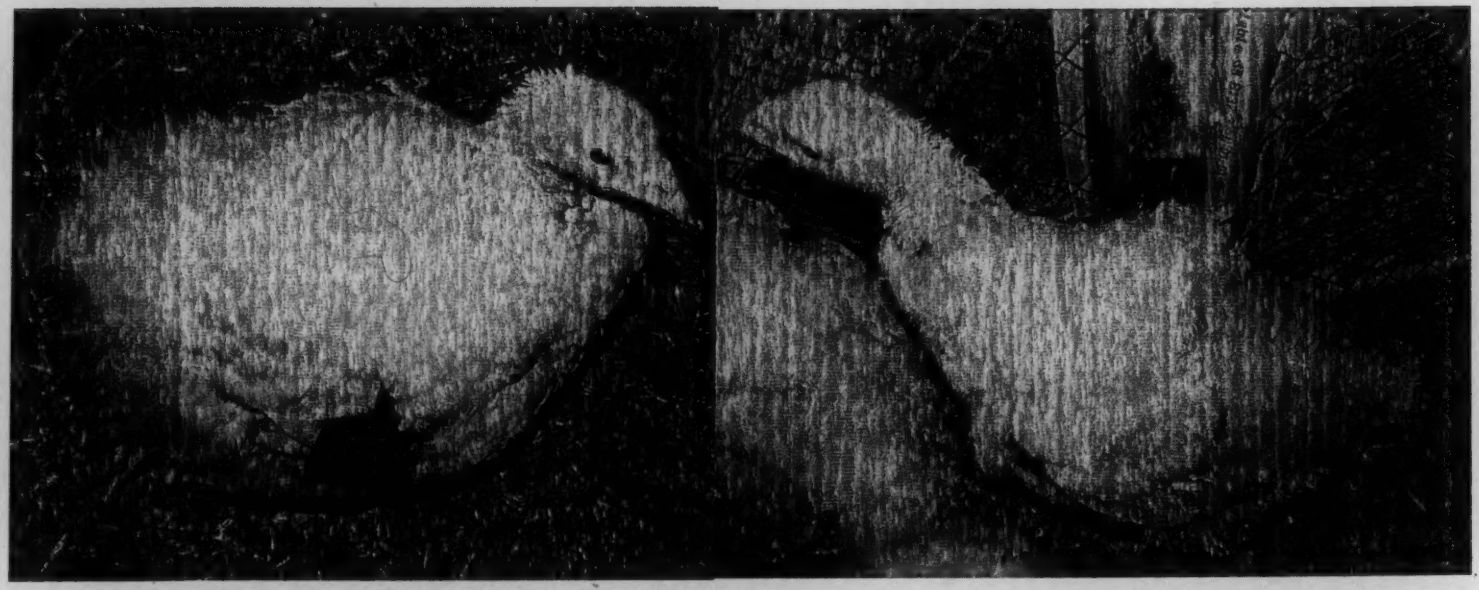
This picture shows the nest box modifications described in the appendix.



This series of pictures represents an example of feather development over time in a slow-feathering turkey hen. It was not possible to obtain a series of pictures from one bird over time due to mortality, but where possible, another bird with similar feather cover was selected to be photographed.



This series of pictures represents an example of the visual variabilty in feather development on the back and wings in slow-feathering turkey hens at approximately 20 wk.



These pictures demonstrate an example of the visual variability in feather cover on the back in slow-feathering turkey hens during the laying period. It could not be determined with certainty whether the difference in feather cover in slow-feathering hens was due to nutrient demand for egg production for hens in production, or if the action of entering the trap nests resulted in increased feather loss on the back due to poor feather quality.